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JOURNAL

OF

THE MADRAS UNIVERSITY

CONTRIBUTIONS IN MATHEMATICS, PHYSICAL AND BIOLOGICAL SCIENCES
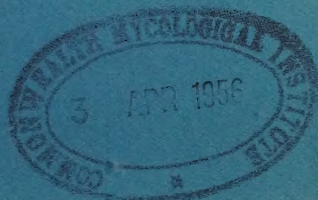
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The manuscript should be typewritten on one side of the paper only, with wide margins and be double spaced throughout including titles, footnotes, literature citations and legends. Symbols, formulae and equations must be written clearly and with great care. Scientific names of genera and species are printed in italics and should be underlined in the typescript. Too many tables, graphs, etc. should be avoided. Each table should be typed on a separate sheet with its proper position marked in the text in pencil.

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Examples :

Text : (Patel, 1948) ; but, e.g., 'Patel (1948) showed that . . . .' . For two authors, write as, e.g., Khanna & Sharma (1947), using the ampersand (&). If there are more than two authors, all names should be given when cited for the first time and thereafter the first name only, adding *et al.*

References :

Raman, C. V. (1949) The theory of the Christiansen experiment. *Proc. Indian Acad. Sci.*, A, 29: 381-90.

Sahni, B. (1936a) Wegener's theory of continental drift in the light of Palaeobotanical evidence. *J. Indian bot. Soc.*, 15: 31-32.

Sahni, B. (1936b) The Karewas of Kashmir. *Curr. Sci.*, 5: 10-16.

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CONTENTS

Migmatisation in Kattriguppe Quarry, Bangalore District, Mysore State

BY

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ABSTRACT

Rocks from Kattriguppe have been chemically analysed. Their Petrography and Petrochemistry are discussed in this paper. The Geochemical changes as given by Reynolds are dealt with. The trend of differentiation has been from amphibolite to quartz-diorite. The effect of the geochemical changes has been to produce rocks of normal igneous series by the process of mechanical pulverisation and reciprocal reaction.

The Kattriguppe quarry lies (77°34′ E long and 12°55′ W lat) ¾th mile southwest of Mount Joy quarry. The chief rock types are granosyenite, granodiorite, quartz-diorite, and amphibolite.

Geology:—

The original rock formation of this area, before the intrusion of acidic injections, is hornblende schist. This schist has been subjected to various degrees of digestion and alteration resulting in the following rock types.

1. Coarse-grained Quartz-diorite
2. Fine-grained Quartz-diorite
3. Grano-diorite
4. Banded gneiss (Granosyenite).

There are lenticular, elongated, dark xenolithic patches of biotite schist in the coarse-grained quartz-diorite. These patches were originally hornblende schists, where the hornblende has now been converted into biotite. Relics of hornblende are found in these patches passing into biotite flakes. These patches are of various sizes, from small patches of 3″ × 6″ to big patches of 3 to

4 feet in breadth and 10 feet in length. They have a general trend of elongation in a N-S direction. Veins of acidic material composed of quartz and felspar cut across the basic patches. These veins start from the coarse-grained quartz-diorite and are pegmatitic and aplitic in character. On account of veining these basic patches are rendered gneissose. The gneisses vary from crudely banded gneisses to well banded gneisses of granosyenitic character. These bands have also undergone contortions and foldings, due to pressure acting on them during their formation. The gneisses strike N-S with a vertical dip. But to the north of the quarry they show an easterly dip of 75°.

The basic patches by partial assimilation have been converted to granodiorite and diorite. They are medium to fine grained phenerocrystalline rocks. The basic minerals of these rocks may be either biotite or hornblende or both.

The gneisses, coarse-grained quartz-diorite, and fine-grained quartz-diorite run in a N-S direction as distinct bands without any apparent order laterally.

All these rock types have been later traversed by pegmatites and aplitic veins. Pegmatites are more numerous than aplites and are of earlier origin. The pegmatite is greyish-white in colour, highly coarse-grained with big crystals of square shaped orthoclase felspars varying in size from $\frac{1}{2}''$ to $1''$, in which are disposed greasy colourless irregularly shaped small grains of quartz. The material in the granosyenite is the same as that found in pegmatite, and as such it may be reasonably concluded that pegmatite has played a prominent part in the conversion of hornblende schist.

Aplite is the youngest intrusive phase as it cuts across not only diorites and gneisses but also pegmatite veins. Aplite has not played any part in the granitisation of the hornblende schist, as it was devoid of gaseous constituents, which are essential to bring about granitisation.

Petrography:—

The rocks are named on chemical grounds and on comparison with Niggli magma types. The chief rock types are:

Amphibolites:—

Amphibolite is a hard, dark, compact looking rock. It is fine-grained in hand specimen. The chief minerals present are quartz, plagioclase, hornblende, biotite, sphene.
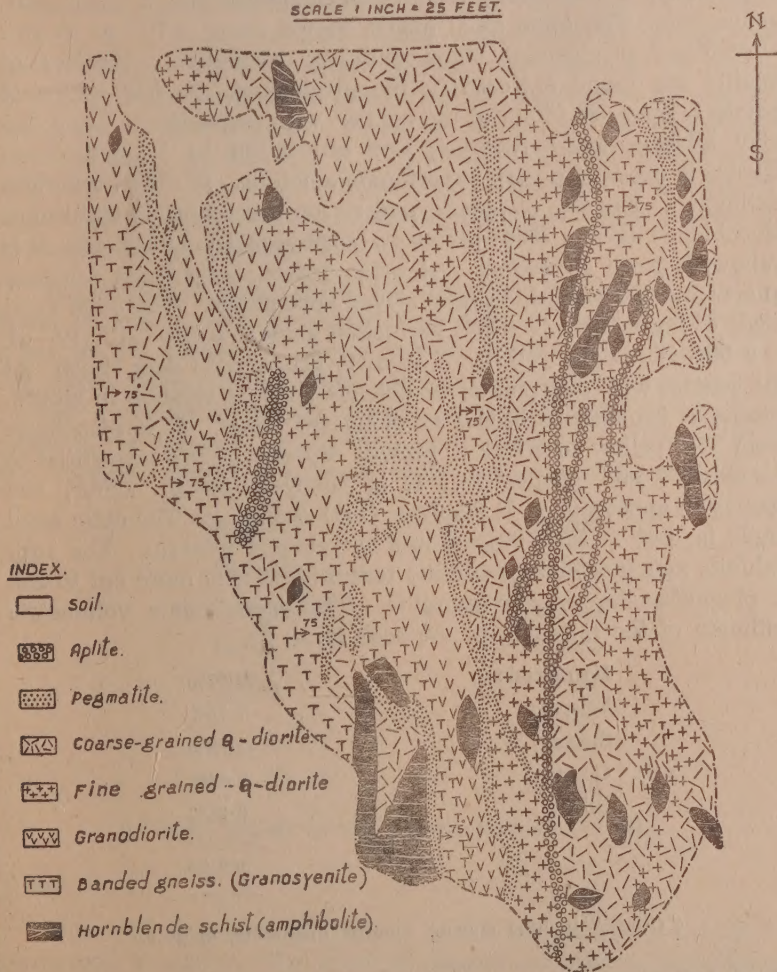
FIG. 1

Under the microscope felspars occur in the interstices of hornblende and are kaolinised. Majority of the plagioclases are untwinned, but a few grains show polysynthetic twinning lamalle. The anorthite content of the plagioclases range from 35%-45%. Out of the 23 grains determined for twin laws, 4 gave albite law, 2 albite-ala, 1 carlsbad, 2 manebach, 12\manebach-ala=acline, 2 manebach-acline=ala. The optic axial angles varied from − 75° to + 85°. Untwinned plagioclases show undulose extinction. Needles of apatite are found enclosed in the plagioclase. A few grains of potash felspar are found at the contact with pegmatites. They display albite-carlsbad twinning and are found to be orthoclase. Quartz is present in very subordinate amounts. It shows undulose extinction. Needles of apatite and zircon are found as inclusions. Hornblende (Babu, 1954) occurs as porphyroblasts and plates. It is yellowish-green in colour. At some places hornblende encloses quartz and sphene exhibiting a sieved appearance. The optic axial angle of hornblende is −65°, extinction angle $Z \wedge C = 18°$, $(\gamma − \alpha) = 0 \cdot 024$, $X =$ light yellow, $Y =$ dirty green, $Z =$ dark green. At the contact with plagioclase, hornblende shows alteration to biotite. Biotite is brown and occurs as elongated flakes. It is pleochroic from $X =$ yellow to $Y = Z =$ brown. Sphene occurs interstitial to hornblende and plagioclase. It is honey-brown in colour, and spongy in appearance. It displays (100) twinning. The optic axial angle is +40°. Magnetite occurs as released mineral. The rock exhibits xenomorphic—granulitic texture and it is more apt to call it plagioclase-hornblende-granulite. The approximate volumetric estimate of the minerals in the rock is: —

Hornblende	..	69·92%
Felspars	..	7·75%
Biotite	..	12·88%
Quartz	..	3·24%
Others	..	6·21%
		100·00

("Others" include sphene, apatite, magnetite, epidote.)

Banded Gneisses (Granosyenite):

They are light grey to greyish-white in colour. The mafic minerals are arranged linearly giving a well-banded appearance to the rock. The minerals present are chiefly quartz, potash felspars, plagioclase, myrmekite, biotite, and hornblende.

Under the microscope quartz shows elongation and the elonga-
tion ratio of some of the grains is as high as 3:1. They display un-
dulose extinction. Felspars are represented by microcline and
plagioclase. Microcline forms the major bulk of the felspars of the
rock. They occur as twinned and untwinned grains. Untwinned
grains show characteristic wavy extinction. They exhibit well de-
veloped two sets of cleavages, namely, murchisonite cleavage and
basal cleavage. The optic axial angles varied from —83° to —87°.
Microcline is not fresh and it is mylonitised. Majority of the plagio-
clases are untwinned. The anorthite content of the plagioclase
felspars range from 22%—32%. The optic axial angles varied from
—73° to +87°. Out of the six grains determined for twin laws, all
of them gave albite law. Myrmekite is developed at the contact of
microcline and plagioclase.

Biotite occurs elongated in the direction of gneissosity and is
brown in colour. It is pleochroic from yellow to brown. At places
it has altered to chlorite. Hornblende is found as elongated plates,
and shows alteration to biotite. Epidote and sphene occur as im-
portant accessories. Apatite occurs as needles and as irregular
grains in the felspars. Magnetite occurs as released mineral. The
approximate volumetric estimate of the minerals in the rock is:—

Quartz	=	14·68%
Microcline	=	58·19%
Plagioclase	=	20·26%
Biotite	=	5·55%
Others	=	1·32%
		100·00

("Others" include epidote, sphene, magnetite, apatite.)

Grano-diorite:

The rock is a medium grained phenerocrystalline rock. It is
mesocratic in colour. The minerals present are quartz, plagioclase,
microcline, myrmekite, biotite and hornblende.

Quartz occurs as anhedral grains and shows undulose extinc-
tion. Prismatic needles of apatite occur as inclusions in quartz.
Plagioclase is fresh and unaltered. It exhibits polysynthetic twin-
ning. Out of the seven grains worked for twin laws, 1 gave albite

law, 3 albite-ala, 3 manebach law. The anorthite content ranges from 20% to 38%. The optic axial angles vary from −78° to +88°. Microclines show wavy extinction and are mylonitised. They exhibit well developed (15. 0. 2) cleavages. At the contact of plagioclase and potash felspars we find the development of myrmekite.

Biotite is the most predominent mafic mineral, and it is found to have resulted due to alteration of hornblende. Biotite in its turn is found altering to chlorite. Pleochroic haloes are present in biotite and zircons are found as inclusions in biotite. Epidote is present abundantly as the chief accessory. It is yellowish-green in colour, and is pleochroic from pale yellow to pistachio-green colour. It gave an optic axial angle of − 74° (by projection). Birefringence is very strong, namely $(\gamma - \alpha) = 0 \cdot 029$. The rock exhibits holocrystalline-hypidiomorphic texture. The approximate volumetric estimate of the minerals in the rock is : —

Quartz	=	20·10%
Microcline	=	20·40%
Plagioclase	=	37·82%
Hornblende	=	16·05%
Biotite	=	4·12%
Others	=	1·51%
		100·00

("Others" include epidote, magnetite, sphene, apatite.)

Fine-Grained-Quartz-Diorite:

This is a fine grained phenerocrystalline rock. The essential minerals present are quartz, plagioclase, microcline, biotite and hornblende.

Quartz occurs as anhedral grains and the majority of them do not display undulose extinction as in previous cases. Plates of plagioclase occur abundantly, and they display polysynthetic twinning. The anorthite content ranges from 19% − 32%. Out of the 5 grains determined for twin laws, 3 gave albite law, and 2 albite-ala. The optic axial angles varied from −78° to +87°. Microcline occurs in subordinate amounts as anhedral grains interstitial to plagioclase and hornblende. It is quite fresh, while plagioclase is altered and shows kaolinisation.

Hornblende occurs as big plates, and also as clots. It is yellowish-brown in colour. It is pleochroic, X = yellow, Y = yellowish-green, Z = dark green. The optic axial angle is − 59°, Z Λ C = 19°, (γ − α) = 0·021, Y = b. It shows alteration to biotite. Biotite is present in subordinate amounts altering to chlorite. Epidote and sphene occur as accessory constituents while magnetite occurs as released mineral. The rock exhibits holocrystalline granitic texture. The approximate volumetric estimate of the minerals in the rock is:—

Quartz	=	19·93%
Pot. Felspar	=	15·96%
Plagioclase	=	43·29%
Hornblende	=	6·84%
Biotite	=	10·34%
Others	=	3·64%
		100·00

("Others" include epidote, ilmenite, magnetite, apatite.)

Coarse-Grained-Quartz-Diorite:

It is a coarse-grained, phenerocrystalline rock, grey to dark-grey in colour. The minerals present are quartz, plagioclase, microcline, biotite and hornblende. Quartz occurs as anhedral grains and a few show undulose extinction. Microcline becomes subordinate in amount, while plagioclase shows a marked increase. Plagioclase exhibits polysynthetic twinning, the twin lamellae are slightly bent due to strain. The anorthite content of the plagioclase ranges from 27% to 33%. The optic axial angle is −79°. Out of the 5 grains worked for twin laws, 4 gave albite law, 1 albite-ala. Myrmekite occurs at the contact of plagioclase and potash felspars.

Biotite is the predominating mafic mineral. It has resulted due to alteration of hornblende, which occurs in subordinate amount. It is dark yellowish-brown in colour and the pleochroism is X = light yellow, Y = Z = green. It occurs as big laths. Epidote and sphene occur as the main accessories. Apatite and zircon are sparingly present. The rock exhibits holocrystalline hypidiomor-

phic texture. The approximate volumetric estimate of the minerals in the rock is: —

Quartz	=	20·93%
Pot. Felspar	=	14·49%
Plagioclase	=	43·78%
Biotite	=	10·86%
Hornblende	=	5·10%
Others	=	4·84%
		100·00

("Others" include epidote, sphene, magnetite, apatite.)

Aplite:

It is fine-grained and greyish-white in colour. Here and there we find mafic minerals occuring as clots and streaks. They are mostly hornblende and biotite, altering to epidote. Mafic minerals are present in very subordinate amounts. Felsic minerals are mostly quartz, microcline and plagioclase. Both the felspars are present in equal amounts. Microcline is quite fresh and shows cross hatching. The anorthite content of the plagioclase ranges from 18% to 27%. Out of the 7 grains determined for twin laws 5 gave albite-ala, 2 albite law. Microcline-perthite is also seen. Quartz is found as irregular and rounded grains. Epidote is the chief accessory mineral. The approximate volumetric estimate of the minerals in the rock is: —

Quartz	=	34·81%
Microcline	=	30·07%
Plagioclase	=	31·39%
Biotite	=	2·81%
Hornblende	=	0·79%
Others	=	0·13%
		100·00

("Others" include epidote, magnetite.)

Felspars:

The twinned and untwinned nature of the plagioclase was established on Universal stage. The ratio of twinned to untwinned grains and the ratio of simple to complex twins are plotted in U. A. C., diagram after Gorai (1951). The plot for the gneiss of granosyenitic composition lies midway on the U.A. side, and therefore coincides with his plots for metamorphic rocks. The plot for granodiorite lies in the igneous field of this diagram for plutonic rocks. But, the plots for quartz-diorites and amphibolites do not coincide with either the metamorphic or the igneous field of Gorai. In fact the proportion of untwinned felspars as determined by the present author is greatest in quartz-diorites, a result contrary to that of Gorai (1951).
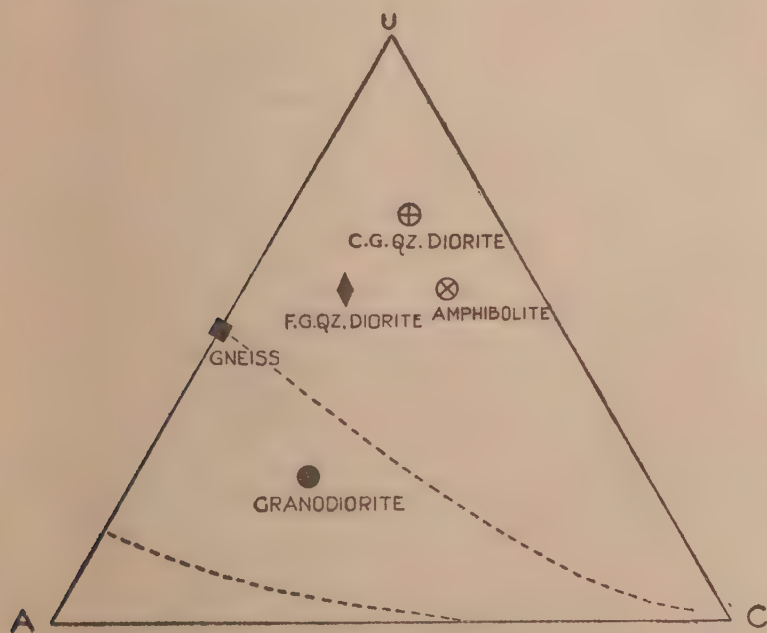
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GORAI. M. Amer. Min. 36. p. 892

Petrochemistry:

The chemical composition, C. I. P. W. Norm, Niggli Values and Niggli Basis are given in Table I.

S. 2

TABLE I.

	Constituents		A	B	C	D	E
1.	SiO_2	..	47·65	65·31	64·50	66·06	71·64
2.	TiO_2	..	1·59	0·18	0·33	0·25	0·07
3.	Al_2O_3	..	16·26	16·86	15·02	18·29	13·30
4.	Fe_2O_3	..	0·56	0·62	0·02	1·63	0·66
5.	FeO	..	11·25	2·75	5·56	2·43	0·78
6.	MnO	..	0·28	0·10	0·22	0·01	trace
7.	MgO	..	6·65	1·29	1·49	1·65	0·53
8.	CaO	..	11·85	1·97	5·52	4·31	2·73
9.	Na_2O	..	2·57	5·35	3·34	3·11	4·47
10.	K_2O	..	1·17	5·68	2·67	1·44	4·97
11.	P_2O_5	..	0·09	trace	0·01	0·06	0·01
12.	H_2O+	..	0·58	0·22	1·13	0·35	0·96
13.	H_2O-	..	0·07	0·17	0·01	0·03	0·22
	Total	..	100·57	100·50	99·79	99·61	100·34
	Sp. Gr.	..	3·12	2·95	2·90	2·86	2·69

A. Amphibolite, Analyst—S. K. Babu.
B. Banded Gneiss (Granosyenite), Analyst—S. K. Babu.
C. Granodiorite, Analyst—S. K. Babu.
D. Coarse—grained Quartz—Diorite, Analyst—S. K. Babu.
E. Granite Aplite, Analyst—S. K. Babu.

NIGGLI VALUES.

Constituents		(a)	(b)	(c)	(d)	(e)
si	..	101·0	254·0	240·0	262·0	354·0
al	..	20·41	38·79	32·81	42·73	38·58
fm	..	42·73	18·69	26·11	22·44	9·49
c	..	27·04	7·47	21·87	18·38	14·24
alk	..	7·27	34·35	18·30	15·52	37·40
k	..	0·26	0·42	0·35	0·23	0·42
mg	..	0·49	0·40	0·31	0·44	0·41
Ti		2·55	0·70	0·89	0·95	0·29

NIGGLI BASIS

Constituents		A	B	C	D	E
Kp	..	14·91	20·04	9·93	5·14	24·58
Ne	..	13·75	28·58	18·14	17·12	17·84
Cal	..	16·87	2·96	11·13	13·18	0·67
Cs	..	1·31	1·48	2·82	—	3·70
Fa	..	13·15	0·64	—	0·85	0·93
Fo	..	24·24	2·63	3·17	0·33	1·09
Fs	..	0·66	3·29	6·93	2·82	—
Ru	..	1·09	0·16	0·23	0·23	0·06
Cp	..	—	—	—	—	—
Sp	..	—	—	—	6·33	—
Qz	..	24·02	40·22	47·65	54·00	50·78
Total	..	100·00	100·00	100·00	100·00	100·00

NORM:

		A	B	C	D	E
Orthoclase	..	8·34	33·92	16·32	8·34	29·74
Albite	..	13·36	45·59	27·77	26·20	38·25
Nephelene	..	4·69	—	—	—	—
Anorthite	..	8·63	5·00	18·07	20·57	1·11
Corundum	..	—	—	—	4·08	—
Diopside	..	24·00	4·18	7·83	—	4·29
Wollastonite	..	—	—	—	—	2·90
Hypersthene	..	—	5·47	9·86	6·61	—
Olivine	..	16·74	—	—	—	—
Magnetite	..	0·93	0·93	—	2·32	0·93
Ilmenite	..	3·04	0·46	0·61	0·61	0·15
Apatite	..	0·34	—	—	0·34	—
Quartz	..	—	4·38	18·36	30·12	30·18
H_2O	..	0·65	0·39	1·14	0·34	1·18
Total	..	100·72	100·32	99·76	99·57	100·30

	SiO₂	Al₂O₃	Fe₂O₃	FeO	MgO	CaO	Na₂O	K₂O	MnO	TiO₂	P₂O₅
Granite aplite / Amphibolite	⊙	+	−	⊕	⊕	⊕	⊙	⊙	⊕	⊕	⊕
Amphibolite / Banded Gneiss	⊕	+	+	⊙	⊙	⊙	⊕	⊕	⊙	⊙	⊙
Banded Gneiss / Granodiorite	−	−	−	⊕	+	⊕	⊙	⊙	⊕	⊕	+
Granodiorite / Quartz–diorite	+	+	+	⊙	+	⊙	−	⊙	⊙	⊙	+

Fig. 3

The rock types of this area afford very good evidence for the mechanical pulverisation and reciprocal reaction theory of *Nockolds* (1933) The sequence of geochemical changes that have resulted are shown (Fig. 3) after the method of *Reynolds* (1946) as follows: The geochemical change is first silicification from amphibolite to granosyenite, followed by basification resulting in granodiorite and further followed by silicification resulting in Quartz-diorite. To start with we have in the amphibolite depression of silica and alkalies and culmination of cafemic constituents and minor constituents-TiO_2, MnO, P_2O_5. As we pass from amphibolite to granosyenite, we find culmination of silica and alkalies and depression of cafemic and minor constituents. Further from granosyenite to granodiorite there is removal of silica and depression of alkalies and addition of cafemic constituents and minor constituents. Further as we proceed from granodiorite to quartz-diorite there is addition of silica and removal of alkalies. These geochemical evidences are supported by mineralogical changes.

The mineralogical evidences are as follows:—

First the plagioclase-hornblende-granulite (amphibolite) is attacked by acidic alkaline intrusions, and hornblende is converted into biotite, plagioclase into myrmekite, resulting in gneisses of granosyenitic character. Further due to conversion of hornblende to biotite, lime is released and there is culmination of lime and TiO_2 as indicated by the presence of accessories sphene and epidote, resulting in grano-diorite. Later myrmekite is formed by the breaking of plagioclase and quartz is released, and there is further enrichment of biotite due to conversion of hornblende by potash, with the result the rock contains abundant biotite and potash felspar in minor amount. With the lime and soda released from hornblende, plagioclase becomes abundant resulting in quartz-diorites.

Q. L. M. values after *Von Wolff* were calculated for the rocks analysed and are presented in Table II.

TABLE II

	Mol. %age.	Alkali Felspar	Anorthite	t	Mt.	Augite	Quartz
A.							
SiO_2	50·37	19·72	13·06	—	—	27·47	-8·55
Al_2O_3	10·15	3·62	6·53	—	—	—	—
Fe_2O_3	0·25	—	—	—	0·25	—	—
FeO	9·96		—	—	0·25	9·96	—
MnO	0·25						
MgO	10·53	—	—	—	—	10·53	—
CaO	13·51	—	6·53	—	—	6·98	—
Na_2O	2·67	3·62	—	—	—	—	—
K_2O	0·95						
P_2O_5	0·06	—	—	—	—	—	—
TiO_2	1·27	—	—	—	—	—	—

L = 53·08   M = 53·04   Q = -8·55

	Mol. %age.	Alkali Felspar	Anorthite	t	Mt.	Augite	Quartz
B.							
SiO_2	71·58	58·86	2·38	—	—	5·71	4·83
Al_2O_3	11·00	9·81	1·19	—	—	—	—
Fe_2O_3	0·27	—	—	—	0·27	—	—
FeO	2·59		—	—	0·27	2·39	—
MnO	0·07						
MgO	2·12	—	—	—	—	2·12	—
CaO	2·39	—	1·19	—	—	1·20	—
Na_2O	4·04	9·81	—	—	—	—	—
K_2O	5·77						
P_2O_5	—	—	—	—	—	—	—
TiO_2	0·20	—	—	—	—	—	—

L = 83·24   M = 11·86   Q = 4·83

	Mol. %age.	Alkali Felspar	Anorthite	t	Mt.	Augite	Quartz.
C.							
SiO_2	70·57	32·28	8·54	—	—	9·91	20·30
Al_2O_3	9·65	5·38	4·27	—	—	—	—
Fe_2O_3	—	—	—	—	—	—	—
FeO	5·12	} —	—	—	—	5·32	—
MnO	0·20						
MgO	2·43	—	—	—	—	2·43	—
CaO	6·43	—	4·27	—	—	2·16	—
Na_2O	3·48	} 5·38	—	—	—	—	—
K_2O	1·90						
P_2O_5	—	—	—	—	—	—	—
TiO_2	0·26	—	—	—	—	—	—

L = 60·12   M = 19·82   Q = 20·30

	Mol. %age.	Alkali Felspar	Anorthite	t	Mt.	Augite	Quartz.
D.							
SiO_2	72·85	25·86	11·44	—	—	4·84	31·04
Al_2O_3	11·85	4·31	5·72	1·82	—	—	—
Fe_2O_3	0·07	—	—	—	0·07	—	—
FeO	2·19	} —	—	—	0·07	2·12	—
MnO	—						
MgO	2·72	—	—	—	—	2·72	—
CaO	5·72	—	5·72	—	—	—	—
Na_2O	3·31	} 4·31	—	—	—	—	—
K_2O	1·00						
P_2O_5	0·06	—	—	—	—	—	—
TiO_2	0·27	—	—	—	—	—	—

L = 59·18   M = 9·82   Q = 31·04

These values are plotted in the Von Wolff Q. L. M. diagram after the method of *Reynolds* (1946) (Fig. 4). It is found that the points take up positions, suggesting, that the trend of geochemical changes is to convert amphibolites by successive stages into quartz-diorites.
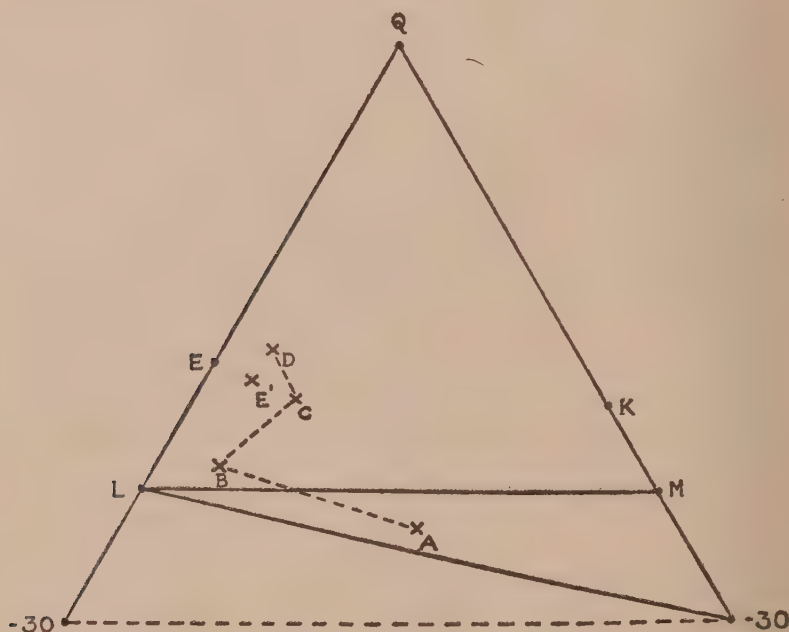

FIG. 4

A. Amphibolite; B. Gneiss (Granosyenite); C. Granodiorite; D. Quartz-Diorite (Coarse-Grained); E. Granite Aplite.

The normative values of Or-Cor, Ab, An-Fem, are plotted in *Brammal's* (1933) diagram (Fig. 5). All the points lie in the igneous field excepting amphibolites, which fall right on the boundary between metamorphic and igneous fields.
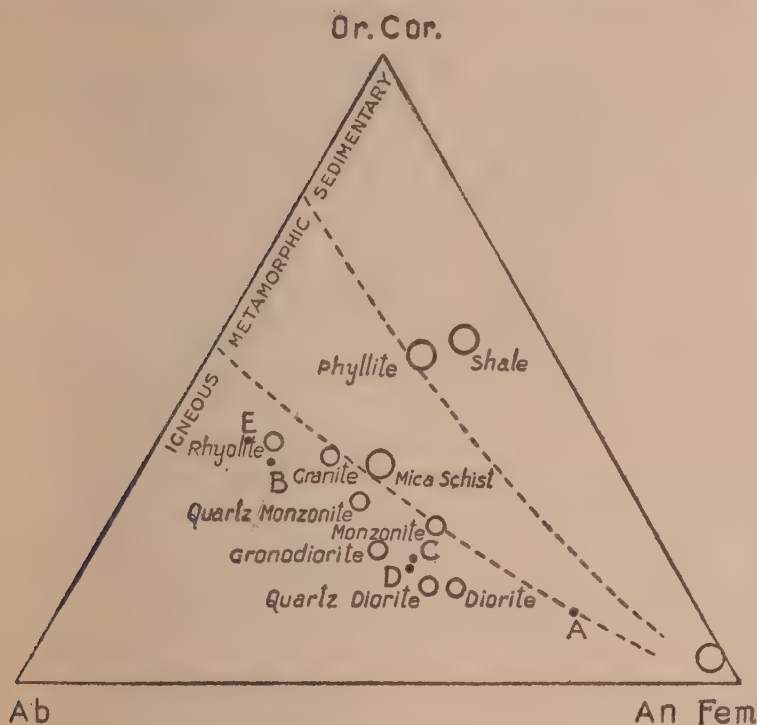
FIG. 5

A. Amphibolite; B. Gneiss (Granosyenite); C. Granodiorite; D. Quartz-Diorite
(Coarse-Grained); E. Granite Aplite.

The trend of differentiation in this quarry has been from amphibolite to quartz-diorite.   The effect of the geochemical changes has been to produce rocks of normal igneous series by the process of mechanical pulverisation and reciprocal reaction.

S. 3

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Heavy Mineral Suites in the Granitic Rocks of Jalarpet

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ABSTRACT

The heavy mineral residue of the granitic rocks of Jalarpet have been prepared and examined. The Index Figure of the heavy residue has been determined. It has been observed that the minerals are distributed uniformly with no striking change in color or form. Apatite, sphene and epidote however, are more abundant in the hornblende-bearing granites than in the biotite-bearing types.

Introduction:

Recently much interest has been evinced in the study of heavy minerals of igneous rocks for purposes of correlation. This study also includes the amount of variation in the heavy mineral suites in a single composite granite mass. This paper deals with the heavy accessory minerals of a composite granite mass near Jalarpet Railway Station. (Long. 78°34′ Lat. 12°34′).

Laboratory Procedure:

The samples were collected from *Yelagiri Hills,* near Jalarpet Railway station. Samples with a wide range of texture were selected for study. Approximately 100 grams of each rock was crushed in an iron mortar to pass through 60 mesh sieve. The material which passed through 60 mesh was discarded. The material retained on the 60 mesh was taken for analysis, and the powdered rock was washed to remove rock flour.

20 grams of the weighed sample was treated with bromoform for the separation of Heavy minerals. The "Heavy residue" thus obtained was weighed and expressed as percentage to give the 'Index Figure', Groves (1927). Despite objections to the term, it is retained.

TABLE I.

No.	Sample	No. of rocks crushed.	Biotite	Hornblende	Normal Accessories.					Pneumatolytic accessory.		Secondary Accessories		
					Zircon	Apatite	Sphene	Magnetite	Ilmenite	Pyroxene	Rutile	Epidote	Zoisite	Haematite
1.	Granite-Gneiss	2	50·9	23·7	1·8	1·9	7·3	1·5	2·3	—	0·5	6·5	1·5	2·1
2.	Grano-diorite	1	5·8	58·9	0·5	3·5	8·4	1·4	1·8	0·8	1·9	12·8	2·7	1·5
3.	Biotite-Granite	1	43·8	26·3	1·5	0·8	8·9	1·1	2·1	—	0·7	9·2	3·5	2·1
4.	Fine Grained Pink Granite	2	7·5	49·5	0·9	4·2	12·2	2·5	2·2	0·8	4·3	12·2	2·2	1·5
5.	Pink Porphyritic Granite	1	9·2	48·7	0·4	2·4	17·3	2·1	3·0	—	5·3	8·9	1·1	1·6
6.	Fine Grained Grey Granite	3	16·3	41·5	1·0	3·7	13·2	2·2	2·8	—	2·8	11·3	3·8	1·4
7.	Porphyritic Grey Granite	2	12·2	54·4	0·7	2·5	7·5	2·1	3·1	—	2·5	11·5	2·3	1·2
	Average	—	20·8	43·3	1·0	2·8	10·7	1·8	2·5	0·2	2·6	10·3	2·4	1·6

Examination of the Residue:

The Heavy residue was passed under horse-shoe magnet and was separated into two fractions referred to as magnetic and non-magnetic. As the entire sample of the non-magnetic residue was too large to be studied, three slides mounted of this material were counted fully. The results of the average of the three counts, expressed as percentage of the total minerals as determined by grain count, are presented in Table I.

To aid comparison the analyses of the non-magnetic minerals have been graphically plotted after Stark and Barnes (1935).

Discussion of the Graph:

Each curve represents a single analysis. Inspection reveals that approximately the same suite of minerals is found in all the specimens. In the description attention is restricted to the normal accessories zircon, apatite, sphene, paying minor attention to such species as hornblende and biotite, which flood the sample. Importance has been attached to the shape of the curve but not to the actual height. The curves are all characterized by low zircon, moderate and high frequency of apatite and sphene, Rutile is also well established in all the specimens.

Material:

The following paragraphs present short megascopic descriptions of the rock samples subjected to this study.

Gneissic-Granite: is a fine grained rock presenting gneissic bands, the felsic and mafic minerals constitute the alternate bands. Two specimens have been crushed for study. Index Figure varies from (5-12). The heavy suite consists of zircon with a maximum of (1·8%), sphene (7·3%), apatite (1·9%) and Rutile as the least (0·5%).

Grano-Diorite: is a coarse grained dark looking rock with phenocrysts of grey felspars and hornblende occurring as blotches. It has a high Index Figure 26. The heavy suite consists of epidote (12·8%), Zircon (0·5%), Pyroxene (0·8%), Apatite (3·5%), Sphene (8·4%) and Rutile (1·9%).

Biotite-Granite: is a medium grained rock, the felsic minerals occur as veins with the greatest width measuring 2 cm. The rock presents a crude banding. Index Figure is 9·4. Epidote (9·2%), Zircon (1·5%), Apatite (0·8%), Sphene (8·4%), Rutile (0·7%). These comprise the heavy suite.
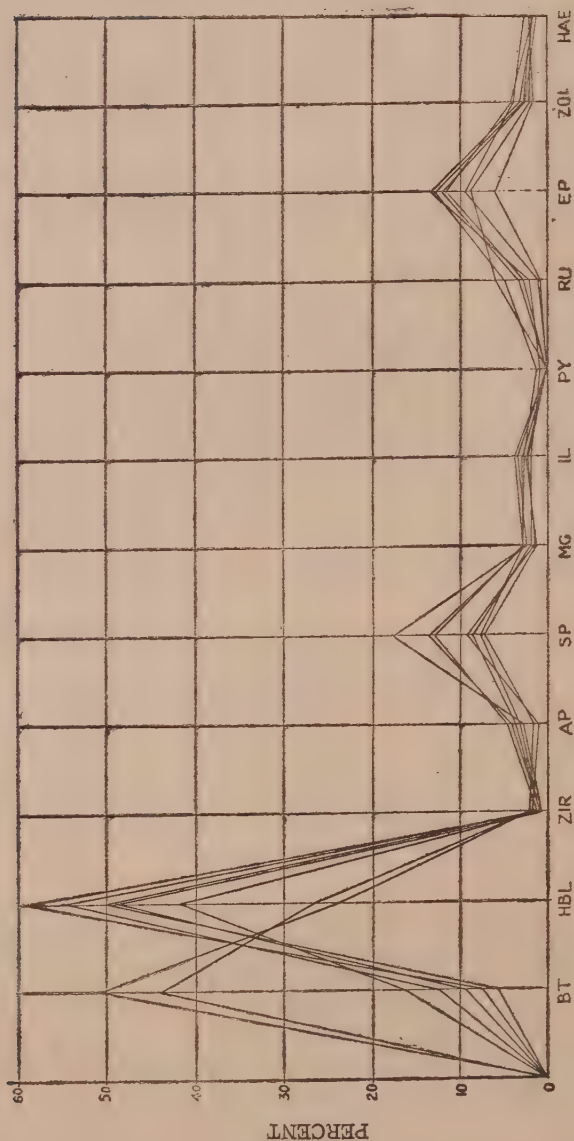
GRAPH SHOWING HEAVY MINERAL ANALYSES OF JALARPET GRANITES.

Fine Grained Pink Granite: is a fine grained rock with pink felspars and needles of hornblende (0·5 c.m. long) occasionally developing as plates (0·4 c.m. × 0·2 c.m.). Two specimens of this type have been crushed. Index figure ranges from 9·5 to 12·4. The heavy suite consists of Epidote (12·2%), Zircon (0·9%), apatite with a maximum of 4·2%, sphene (12·2%) Pyroxene (0·8%), and Rutile (4·3%).

Pink-Porphyrytic Granite: is a coarse grained pinkish looking rock with phenocrysts of pink felspars and plates of hornblende (0·5 c.m. × 0·3 c.m.). Index Figure is 7·5. The heavy suite consists of Epidote (8·9%), Zircon (0·4%), Apatite (2·4%), sphene (17·3%), the largest incidence in the series, and Rutile with a maximum of (5·3%).

Medium Grained Grey Granite: is a medium grained rock with hornblende occurring as granules and needles (0·4 c.m.). Three samples have been crushed. Index Figure ranges from (12·4 — 17·0). Epidote (11·3%), Zircon (1%), Apatite (3·7%), Sphene (13·2%), Rutile (2·8%), comprise the heavy suite.

Porphrytic Grey Granite: is a coarse grained greyish rock with phenocrysts of grey felspars. Hornblende is crudely lineated. Two samples have been crushed. Index Figure ranges from (10-16). The heavy suite comprises of Epidote (11·7%), Zircon (0·9%), Apatite (2·9%), Sphene (9·8%) and Rutile (2·3%).

Minerals :

The following paragraphs list the minerals seen in the residue with their characters.

Zircon : Occurs as colorless grains. Euhedral grains (0.22 m.m. X 0.17 m.m.) are also encountered. The grains are mostly colorless, and occasionally pale brown in color with no inclusions.

Apatite : Occurs as colorless grains. The grains are prismatic (0.24 m.m. X 0.17 m.m.) or rounded. Dark inclusions are fairly common.

Sphene : Occurs as irregular fragments (0.41 m.m. X 0.33 m.m.). Wedge shaped grains with (100) twins are also encountered. The color ranges from pale yellow to yellow or yellowish brown.

Epidote : mostly occurs as anhedral grains (0.28 m.m. X 0.16 m.m.). They are either colorless or pistachio-green colored and are identified by their high order of interference colors.

Zoisite : occurs as anhedral (0.22 m.m. X 0.16 m.m.) pale yellow grains. They are characterized by low interference color, occasionally exhibiting ultra-blues and ultra-yellows.

Rutile : occurs as anhedral grains (0.47 m.m. X 0.30 m.m.). The color ranges from yellow or orange to deep red or brown and shows moderate dichroism.

Summary and Conclusion :

The general character of the heavy concentrates vary very little in spite of the wide range in Index Figure. In the description attention has been confined to the normal accessories, Zircon, apatite, sphene, paying minor attention to Biotite and Hornblende, which flood the sample. Sphene is the most abundant accessory mineral and Zircon is the least abundant in the series. The average of Jalarpet granitic rocks gives Zircon : apatite : sphene ratio 1 : 3 : 11. Rutile is well established in the series.

Two broad types of granites, however, can be differentiated in the mass,—one characterised by the abundance of hornblende, and the other by the abundance of biotite. The hornblende rich varieties have a higher proportion of the accessories—Apatite, Sphene, epidote and rutile. Zircon is slightly higher in the biotite rich types. The distribution of the accessories seems to indicate stages in granitization of amphibolites of the area by invading feldspathic solution. A map of the distribution of the accessories both laterally and with depth is under preparation.

My thanks are due to Dr. P. R. J. Naidu for his suggestions and constructive criticism.

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The Association and Genesis of Wollastonite, and Scapolite Bearing Rocks of Sankaridrug, Salem District

BY

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ABSTRACT

The wollastonite and scapolite bearing rocks of Sankaridrug have been studied. The contact metamorphic assemblages developed in the calc-bands are discussed in the light of Eskola's facies. The geological and tectonic relationship of the anorthite-gneiss of Sittampundi to the calc-gneisses of Sankaridrug is suggested.

The Wollastonite and scapolite rocks occur in the area lying between lat. 11°25' — 11°31' N and long. 77°47' — 77°56' E comprised in the Survey of India sheets $58\dfrac{E}{14}$ and $58\dfrac{E}{15}$ The presence of calc-gneisses and associated rocks in this area have been reported by Lacroix (1891). Apart from some studies of the calcite for industrial purposes no detailed work is on record. The greater part of this area consists of granites and pegmatites, which have invaded the country rocks, mainly biotite-gneiss (garnetiferous), calc-bands and amphibolites. The crystalline limestone with a variable impurity content is invaded by the granite. The action has produced typical contact metamorphic assemblages. Prior to the intrusion of the acid rocks, the country rocks have been subjected to regional metamorphism. The metamorphic mineral assemblages produced are discussed in this paper.

The field relation between the igneous and metamorphic rocks is of great interest. The calc-bands with their associated rocks show a marked change in their strike along the entire length (Ref. Map). The bands pass through Devanakavundanur, Mavelipalayam, Unjanur towards Kolikalnattam. They become fewer and narrower towards the south and are seen as discontinuous bands upto Vakkilipatti. The strike changes from N. 75° W — S. 75° E

S. 4

(Devanakavundanur) gradually to N 20° W — S 20° E at Maveli-palayam. The outcrop is crescentic with its convexity pointing to the N.E. with moderate to steep dips towards N. Further south, the strike changes to N-S. The dip on the N.W. part is about 50° and in the southern extremity exceeds 60°. The isolated band near Pudupalayam has N-S strike dipping 60° to East. Further north, it slightly veers to N.N.E. In this connection it is notable that my colleague Mr. C. E. Nehru has noticed near Sittampundi the anorthite gneiss band also crescentic in shape outcropping with steep southerly dips. On the western side, it strikes N.W.-S.E. changing gradually to E.-W. in the middle of the band and N.E.-S.W. in the East.

GEOLOGICAL MAP
OF
SANKARIDRUG.

INDEX
▭ Granite
▤ Crystalline Limestone
▦ Calciphyre & amphibolites
▨ Garnet-Epidote-pyroxene Rock
▨ Biotite Gneiss

The occurrence of the anorthite gneiss containing calcite veins in Sittampundi and the calc gneisses in Sankaridrug may really mark as one continuous regionally metamorphosed sedimentary calcareous formation, later on intruded by the Sankaridrug granites. The northerly dip of the northern formations (Sankaridrug) and the southerly dip of the southern formations (Sittampundi) are suggestive of a quaquaversal fold. A section across the two areas is being produced by my colleague (in this issue of the

Madras University Journal). The presence of eclogite in Sittam-
pundi and its absence in Sankaridrug shows that the metamor-
phism in the southern area was more intense while in the San-
karidrug area, it is of the contact metamorphic type. The presence
of minerals like scapolite, vesuvianite and phlogopite and their
rarity in Sittampundi area are also suggestive of the greater role
of volatiles in Sankaridrug.

The granite extends beyond the calcite bands also. This indi-
cates that the position of the calc-bands is to be reckoned as blocks
sunk in the magma, parts of them being stoped away. This is
indicated by the presence of discontinuous patches of calc-gneiss,
biotite-gneiss and amphibolites in random orientation throughout
the area.

PETROGRAPHY

Granite : The granite is a fine to medium grained pink or
grey rock with a very high ratio of leucocratic to melanocratic
components. The only matic components are a few occasional flakes
of brown biotite associated with iron ores. Apatite and sphene
occur as accessories. The rock has a typical equigranular, hypi-
diomorphic texture. It consists of quartz, microcline, plagioclase
and a few flakes of biotite. The microcline shows typical grating
structure. The plagioclase is mainly oligoclase (15% to 25% An),
with a shell of albite in some specimens. The twinning is after
Albite law and Albite ala-B law. There are pericline lamellae across
the grains twinned on Albite law. Some microperthite is also
present.

Biotite-gneiss : The country gneiss is a highly foliated rock.
The minerals include biotite, plagioclase, microcline, and quartz.
The anorthite content varies between 14 and 25%. The twinning
is commonly after albite law with a few grains twinned on the
pericline law. Reddish brown garnets occur in some localities. In
many places the biotite gneiss is migmatised by veins of granite and
pegmatites along the foliae. The pegmatite displays a pinching and
swelling structure. There are also ptygmatic foldings of the peg-
matite and quartz veins.

Amphibolites : Amphibolites with a dark green hornblende
are common. The amphibolites have been migmatised by the
intruding granites as is evidenced by the occurrence of clusters of
pyroxene, hornblende, sphene and epidote in a felsic groundmass
of microcline, quartz and very little plagioclase. The assemblage
here is suggestive of migmatisation.

Calc-rocks :   The Crystalline limestone, occasionally dolomitic, ranges from fine-grained marble to very coarse-grained calcite. In the coarse-grained varieties, the pinkening is associated with pyroxene and hornblende.

MINERALOGY

Wollastonite is generally in small crystals pseudo-prismatic on 'b'. It occurs as needles in alternate laminae as well as in diversely oriented groups. (100) cleavage is prominent. A number of crystals are twinned on (100). It is colourless and some grains tend to be fibrous. The optic axial plane is at right angles to the elongation. The mineral is attacked by HCl. The optical data are

$-2V = 38°$ (average of 23 readings).

$X \wedge c$ determined by a method, analogous to that of Nemato and Turner (1942) applied to twins of pyroxenes and amphiboles, is 31° (average of 25 readings).

$$b = Y., \ XZ \parallel (010)$$

The optical data indicate that the mineral is the monoclinic variety, namely para-wollastonite.

The garnet is colourless to pale grey in thin section, is generally in small grains with rounded faces. It is intimately associated with diopside. The specific gravity is $3 \cdot 65$ and R.I. $= 1 \cdot 775$ It is identified as grossularite.

The common pyroxene is pale green, with $+2V = 60°$ (average of 4 readings) and $Z \wedge c = 39°$. On Wager—and Deer's curves (1938) the composition is $Wo_{55} \ En_{40} \ Fs_5$.

Epidote is present as pale-yellow grains with high relief and large optic axial angle. There is no distinct pleochroism. $-2V = 78°$ to $80°$ and $X \wedge c = 1°$ to $3°$. The presence of grains twinned on (100) with (001) cleavage gives rise to herringbone appearance in some grains.

Vesuvianite is secondary after grossularite. There is no grain which shows distinct crystal faces. It is colourless in thin section, optically uniaxial, negative. It is developed as a thin rim around garnet. There are also some grains which show abnormal biaxial characters and distinct dispersion.

Scapolite is distributed as colourless grains with high bire-fringence (ω-$\varepsilon = 0.033$). It occasionally exhibits fibrous struc-ture. It is uniaxial, negative, with two sets of cleavages. It is known to occur along with pyroxenes and also with plagioclase.

Apart from these there are palegreen needle-like crystals of amphiboles. $-2V = 88°$ and $Z \wedge c = 18°$ with positive elongation. These belong to the actinolite-tremolite series, mainly actinolitic.

The presence of colourless amphibole (in thin section) with positive optic axial angle of 80° and $Z \wedge c = 22°$ is of interest. It is edenite.

The following mineral assemblages have been noticed : —

    1.   Calcite — actinolite

    2.   Calcite — diopside — actinolite

    2-a. Calcite — diopside.

    3.   Calcite — phlogopite — edenite

    4.   Calcite — diopside — garnet

    5.   Wollastonite — diopside —grossularite

    6.   Garnet — diopside — vesuvianite

    7.   Grossularite — diopside — wollastonite — vesuvianite

    8.   Pyroxene — scapolite — calcite

    9.   Diopside — calcite — scapolite — plagioclase — quartz — microcline

   10.   Microcline — quartz — diopside — calcite

   11.   Calcite — diopside — plagioclase — quartz — micro-cline.

The conformable dip of the calc — bands with the biotite gneiss and amphibolite and the crystalline nature of calcite, are indica-tive of the fact that original calc-bands are regionally metamor-phosed. These have been subjected to contact metamorphism by the intrusion of granite as a result of which the above assemblages have developed. An originally crystalline dolomitic limestone with SiO_2 and low content of alumina can be assumed.

The first stage is noted by the development of pale green acti-nolite, rather rare, in the form of radiating needles and fibres.

Dolomite $+$ Silica $=$ Actinolite. (No. 1).

A slightly higher temperature gives rise to the assemblage of calcite — diopside — actinolite (No. 2 and 2-a).

A little addition of alumina gives rise to the variety of amphibole edenite. The presence of phlogopite in this assemblage is indicative of halogen metasomatism.

Dolomite $+ SiO_2 + Al_2O_3 =$ Calcite $+$ edenite.   (No. 3).

A little excess alumina goes into the composition of grossularite. Diopside is found in company with this mineral.

When the alumina is exhausted after the formation of grossularite and also at a higher temperature, that is, nearer the contact aureole, the mineral wollastonite develops, and the assemblage wollastonite — diopside — grossularite (No. 5) is common.

At still higher temperature the wollastonite — marble is developed (taking the remaining amount of SiO_2) the assemblage being wollastonite-calcite.

$$CaCO_3 + SiO_2 = CaSiO_3 + CO_2$$

The halogen metasomatism of these rock types has given rise to the assemblage numbers 6, 7 & 8, as is indicated by the presence of the minerals scapolite and vesuvianite.

The assemblages 9, 10 & 11 are interesting. Calcite, diopside and scapolite in number 9 are found to occur in the form of clusters and in number 10 & 11 diopside, calcite, and sphene are found to form fine stringers, parallel to microcline, quartz and plagioclase. These are contaminated rocks, being products of migmatisation, and can be considered to be the equivalent of the migmatized biotite — gneiss and amphibolites.

The presence of the above assemblages, especially the garnet — diopside — wollastonite are characteristic of high temperature. The presence of wollastonite indicates reaction between calcite and quartz and hence low pressure. These points indicate that the rock assemblages belong to the pyroxene — hornfels facies. The presence of epidote assemblage, belonging to the amphibolite facies, indicates a later retrogressive effect suffered by the rock types. This is suggested by the presence of skarns of garnet surrounded by epidote.

Petrochemistry

Both the pink and grey granites, the country rock biotite-gneiss, a calc-silicate rock containing the assemblage diopside-plagioclase-quartz-scapolite, a migmatite and another epidote-pyroxene rock were chemically analysed. Their chemical analyses, C.I.P.W. norm, Niggli values and Niggli basis are set below. There are also a few other analyses given for comparison.

TABLE I

Constituents	A	B	C	D	E	F	G	H	I	J	K
SiO_2	76·37	75·03	76·54	75·65	66·92	65·09	56·90	56·8	49·84	52·31	50·37
TiO_2	0·13	0·02	0·19	0·28	0·44	0·93	0·45	0·8	0·05	0·32	1·06
Al_2O_3	11·86	12·60	11·86	11·89	15·63	16·37	18·22	16·7	14·67	13·12	10·65
Fe_2O_3	1·90	1·42	0·59	1·19	0·81	0·93	1·85	3·2	2·01	3·47	3·02
FeO	0·93	0·54	1·22	1·02	3·39	5·64	3·40	4·4	3·84	4·99	4·13
MnO	0·24	0·02	0·03	0·26	0·07	0·16	0·06	0·1	0·05	0·23	0·22
MgO	0·40	0·59	0·30	0·15	2·36	2·40	2·50	4·2	3·07	3·35	6·39
CaO	0·62	1·14	1·10	0·91	3·55	2·40	10·00	6·7	24·40	14·85	20·84
Na_2O	3·22	4·99	3·06	3·44	3·84	3·31	2·15	3·4	1·36	4·39	1·90
K_2O	4·48	3·11	4·29	4·26	2·27	1·93	3·12	2·1	0·03	1·38	1·60
H_2O^+	0·16	0·28	0·22	0·40	0·80	0·58	0·82	1·4	0·40	0·03	0·20
H_2O^-	0·04	0·06	..	0·41	0·10	0·13	0·18		0·14	..	0·17
P_2O_5	..	0·28	0·02	0·16	0·08	0·11	0·19	0·2	..	0·07	0·07
CO_2	..	..	..	0·09	..	..	..	..	..	0·16	..
Rest	..	..	0·06	0·03	..	0·14	..	..	..	1·55*	..
Total	100·35	100·08	99·48	100·14	100·26	100·12	99·84	100·0	99·86	100·22	100·52

* Includes 1·54 of Cl.

C. I. P. W. NORM

Q	..	38·28	31·68	38·88	37·14	23·16	17·04	9·36	8·64	1·08	1·80	..
Or	..	26·69	18·35	25·58	25·58	13·34	11·12	18·35	12·23	..	8·34	9·45
Ab	..	27·25	42·44	25·68	28·82	31·96	27·77	18·34	28·82	12·05	26·2	8·38
An	..	3·06	2·78	5·56	3·61	16·96	11·12	31·24	24·19	33·64	17·51	16·40
Ne	..	..	..	..	..	..	..	..	..	..	..	3·69
Cor	..	0·61	..	0·20	0·31	0·71	4·90	..	..	..	..	..
Di	..	..	0·86	..	..	..	..	14·93	6·70	26·55	29·55	41·25
Wo	..	..	..	..	..	..	..	..	..	23·00	7·66	14·27
Hy	..	1·40	1·10	2·12	1·19	10·92	14·32	2·99	11·5	..	..	..
Il	..	0·15	..	0·46	0·61	0·76	1·67	0·91	1·52	..	0·61	2·13
Mt	..	2·78	1·62	0·93	1·86	1·16	1·39	2·55	4·64	3·02	5·10	4·41
Ap	..	..	0·67	..	0·34	0·34	0·34	0·34	0·34	..	0·34	0·34
Ct	..	..	..	..	0·20	..	..	..	..	..	0·4	..
Water	..	0·20	0·34	..	..	0·90	0·67	1·00	1·4	0·64	0·03	0·24
Halite	..	..	..	..	..	..	..	..	..	..	2·46	..

Niggli Basis

	1	2	3	4	5	6	7	8	9	10	11
Cp	..	0·22	..	0·28	..	0·28	0·11	0·85	..	0·28	0·11
Kp	15·90	11·06	15·71	15·71	8·10	6·71	11·26	7·45	..	5·08	5·71
Ne	18·60	27·13	16·74	18·79	20·58	17·75	11·36	18·62	7·51	24·04	9·74
Cal	1·86	1·68	3·42	2·22	10·80	6·73	18·55	14·72	20·82	7·11	9·91
Sp	0·68	..	0·34	0·51	0·68	10·02	..	..	..	..	..
Hz	..	..	..	..	..	1·33	..	..	..	..	..
Cs	..	0·84	..	..	..	..	5·68	2·08	26·91	18·74	26·3
Fs	2·03	1·51	0·68	1·37	0·84	1·02	2·01	3·38	2·22	3·73	3·19
Fo	0·51	1·28	0·51	..	4·61	..	4·20	8·91	6·60	7·11	13·43
Fa	1·47	0·56	1·48	1·54	4·16	5·98	4·01	5·25	4·61	6·09	5·04
Ru	0·05	..	0·17	0·23	0·28	0·61	0·28	0·56	0·06	0·23	0·78
Q	58·90	55·72	60·94	59·33	49·94	49·54	41·54	38·20	31·29	27·59	25·80
Q	58·90	55·72	60·94	59·33	49·94	49·54	41·54	38·20	31·29	27·59	25·80
L	36·36	39·87	35·87	36·72	39·48	31·19	41·17	40·79	28·33	36·23	25·36
M	4·74	4·41	3·18	3·93	10·60	19·24	17·29	21·14	40·40	36·18	48·85

Niggli values

	451·4	421·1	480·1	463·3	266·1	252·9	169·6	166·6	109·3	128·2	107·4
Si	451·4	421·1	480·1	463·3	266·1	252·9	169·6	166·6	109·3	128·2	107·4
al	41·5	41·75	44·15	43·01	36·52	37·53	31·84	28·87	18·95	18·82	13·45
fm	19·5	13·47	12·44	13·97	27·93	35·42	24·15	36·45	20·65	29·42	33·05
c	3·9	6·73	7·54	5·88	15·28	10·02	32·03	21·13	57·5	39·12	47·62
alk	35·11	38·05	35·84	37·13	20·28	17·01	11·99	13·56	2·90	12·65	5·89
ti	0·36	0·34	1·1	1·4	1·19	..	0·9	1·7	0·13	0·59	1·79
k	0·475	0·292	0·48	0·45	0·28	0·27	0·493	0·296	..	0·174	0·369
mg	0·182	0·375	0·24	0·10	0·50	0·395	0·467	0·507	0·49	0·42	0·62
Magma type after Niggli	aplo- granit- isch	natron- granit- aplitisch	aplit- granit- isch	aplit- granit- isch		..	..	..	..	..	..

MODAL COMPOSITION

	A	B	E	G	I	K
Quartz	25·68	31·79	28·32	6·78	..	..
Microcline	51·74	47·04	26·26	64·32	19·96	..
Plagioclase	21·27	18·76	28·04	5·44	0·85	29·00
Pyroxene	..	..	..	..	47·93	38·39
Hornblende	..	..	..	16·92	..	..
Biotite	..	..	17·18	..	..	..
Epidote	..	..	..	..	..	25·19
Garnet	..	..	..	..	..	5·10
Scapolite	..	..	..	..	21·68	..
Accessories	1·30	2·39	0·19	6·54	9·63	1·68
An % by Reinhard method	5-10	5-12	25	50-65	75-85	28-30
Normative An %	10·09	6·16	34·67	63·02	73·6	66·18

A. Grey granite, Sankaridrug,: Analyst; M. N. Balasubrahmanyan.

B. Pink granite, Sankaridrug,: Analyst; M. N. Balasubrahmanyan.

C. Roblar Leucogranite, Southern California Batholith, Analyst; E. S. Larsen, (*Geol. Soc. America Bull.* 29. p. 48, 1948).

D. Granite, Arran, Scotland. (G. W. Tyrrell, The geology of Arran, *Scotland Geol. Survey Mem.*, p. 192. No. 9, 1928).

E. Biotite Gneiss, Sankaridrug; Analyst; M. N. Balasubrahmanyan.

F. Quartz — biotite-garnet gneiss, Fort Ann, New York; Analyst; W. F. Hillebrand.

G. Migmatite, Sankaridrug, Analyst; M. N. Balasubrahmanyan.

H. Diorite; Mean of 70 analyses. Quoted by G. W. Tyrrel, The Principles of Petrology, 9th Edn. Methuen & Co., Ltd., p. 112.

I. Pyroxene — scapolite rock; Sankaridrug : Analyst; M. N. Balasubrahmanyan.

J. Scapolite — pyroxene granulite, Cloncurry Dt. N. W. Queensland, Analyst; G. C. Carlos.

K. Epidote — pyroxene rock, Analyst; M. N. Balasubrahmanyan.

The pyroxene — scapolite granulite, reported by Edward and Baker (1953) contains a dipyre. The plagioclase associated with this is albite. When scapolite is absent, albite is present in rocks of N. W. Queensland. They advocate that the rock is a product of soda metasomatism of originally calcareous shales, brought about by large amounts of chlorine. The scapolite of the analysed rock of Sankaridrug contains about 70% of meionite. It is interesting to note that the plagioclase has 75% to 85% of anorthite. Sundius, (quoted by Ramberg, 1952) however says that "regional pneumatolytic metamorphism" is responsible for the regional development of scapolite, unconnected with any igneous intrusion. The development of scapolite in aureoles around granite, soda granite and nordmarkite intrusions has been reported from Oslo district. In Sankaridrug, scapolites occur replacing plagioclase and also with pyroxene rocks in which plagioclase is absent. Hence it is a case of scapolitization of feldspars brought about by the necessary volatiles from the later granite. The divergence between the analysed rock of Sankaridrug and that of N. W. Queensland is easily explicable. The Sankaridrug rock is more calcareous due to the plagioclase and meionitic scapolite while dipyre in N. W. Queensland is due to extra sodic content.

The last rock is a garnet — epidote-pyroxene rock. It occurs around brown garnets of about one foot in diameter and the garnet shows numerous inclusions of the pyroxene. The pyroxene and epidote form alternate layers. Osborne (1932) has stated that epidote occurs as a retrograde product of garnet which is a grossularite (later modified by iron bearing solutions). Beautiful diablastic growths of diopside — grossular pass into similar growths of grossular — clinozoisite. He says that this change is assisted by the activity of solutions such as are prevalent during thermal metamorphism. A similar degradation of andradite — grossular garnet to epidote is recorded by C. E. Tilley, (quoted by Osborne). The garnet occurring in Sankaridrug has a R·I=1·80 and Sp. gr.=3·73. These data indicate the composition of garnet as between grossularite and andradite. The occurrence of big crystals of garnet indicates their origin as 'Skarns'. A similar retrograde effect as has been advocated by Osborne (1932) can be applied to the Sankaridrug occurrence also, as a result of which epidote has developed around garnet.

The mineral assemblages noted in the calc bands of Sankaridrug therefore can be interpreted as mineral facies of the group pyroxene — hornfels facies of Eskola. Retrograde metamorphism accounts for the presence of a subordinate presence of the amphibolite facies. Further work is in progress.

ACKNOWLEDGEMENT

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A Pyroxene from Sittampundi, Salem Dt.

BY

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ABSTRACT

A clinopyroxene from Sittampundi is analysed and its optical characters determined. Its characters are compared with the pyroxenes of Adirondack anorthosite series and its origin discussed.

Towards the South of the anorthite gneisses of Sittampundi there occur bands of garnet-pyroxene rocks. These rocks sometimes show a pegmatitic phase — consisting of coarse pyroxenites. A specimen of nearly pure pyroxene was collected from one such concentrations about 3 miles south-east of Sittampundi village. The exposure (Long. 77° 53° : Lat. 11° 13′) is found on the way from Chinnampalaiyam to the Corundum mines.

The pyroxene collected occurs as a surface exposure and is weathered. The rock as a whole looks greyish green in colour and the crystals are nearly a centimetre in breadth and one to one and a half centimetres in length. The lustre is dull but a bronzy lustre is seen when the mineral is split along the cleavage plane. It is fibrous in nature with a splintery fracture and shows good cleavage.

In thin sections the pyroxene is colourless to pale green in colour and exhibits good cleavages which are close to each other giving the apppearance of fine lamellae. There are cracks present along which Uralitisation has taken place giving rise to small crystals of a brown hornblende. There are also a few grains of an orthorhombic pyroxene which exhibit a very feeble pleochroism and give an optic axial angle of $-70°$.

The pyroxene is chemically analysed and the results are given in Table I. The structural formula as given by Warren on the basis of 6 (O, OH, F) has also been calculated and the calculations shown in the table. The structural formula arrived at is quite in accordance with the structural formula of clino-pyroxenes as given by Berman (1937).

TABLE I

	Wt.%	Mol. Prop.	Oxygen atoms		Metal atoms	6 (O, OH, F)			Valency Check.
SiO$_2$	42·70	0·712	1·424	Si	0·712	1·620		Si^{++++}	6·480
Al$_2$O$_3$	8·55	0·084	0·252	Al	0·168	0·382 {0·380 / 0·002	2·00	Al^{+++}	1·146
TiO$_2$	0·42	0·005	0·010	Ti	0·005	0·011		Ti^{++++}	0·044
Fe$_2$O$_3$	1·80	0·011	0·033	Fe''	0·022	0·050	1·035	Fe^{+++}	0·150
FeO	6·52	0·090	0·090	Fe''	0·090	0·205		Fe^{++}	0·410
MnO	0·16	0·002	0·002	Mn	0·002	0·005		Mn^{++}	0·010
MgO	13·41	0·335	0·335	Mg	0·335	0·762		Mg^{++}	1·524
CaO	24·52	0·438	0·438	Ca	0·438	0·997		Ca^{++}	1·994
Na$_2$O	1·02	0·016	0·016	Na	0·032	0·073	1·093	Na$^+$	0·073
K$_2$O	0·48	0·005	0·005	K	0·010	0·023		K$^+$	0·023
H$_2$O$^+$	0·58	0·032	0·032	OH	0·064	0·146			11·854
H$_2$O$^-$	0·17	—	—					OH	0·146
Total	100·33	—	2·637					O	11·708
									11·854

$$F = \frac{6}{2 \cdot 637} = 2 \cdot 275$$

Formula : (OH)$_{0·146}$ (Ca, Na, K)$_{1·093}$ (Mg, Fe'', Fe''', Al in part, Mn, Ti)$_{1·035}$ (Si, Al)$_2$ O$_{5·854}$

Buddington (1950) mentions that all the pyroxenes of the anorthosite series of Adirondack are richer in alumina and ferric iron than those of normal gabbros and norites. This they account as due to the crystallization of the anorthosite series of rocks in a different environment, either in a chemically different magma, under different physical conditions, or both. It is also noticed that the pyroxenes of anorthosites and associated rocks in general are richer in alumina and calcium and poor in magnesia whereas the pyroxenes of the gabbroic rocks contain nearly equal amounts of calcium and magnesium.

It is of interest to note that the pyroxene under consideration is also rich in alumina and calcium and relatively poor in magnesia. The argument put forward by Buddington and Leonard can be applied to this case also.

The chemical analysis of the pyroxene is compared in Table II to a similar clinopyroxene from Adirondack anorthosite series. Both the pyroxenes are rich in alumina and calcium.

TABLE II

		(1)	(2)
SiO_2	..	42·70	45·80
Al_2O_3	..	8·55	7·06
TiO_2	..	0·42	1·42
Fe_2O_3	..	1·80	3·14
FeO	..	6·52	10·29
MnO	..	0·16	0·20
MgO	..	13·41	8·42
CaO	..	24·52	21·58
Na_2O	..	1·02	0·68
K_2O	..	0·48	0·01
H_2O^+	..	0·58	0·30
H_2O^-	..	0·17	0·10
		100·33	99·00

(1)   Clinopyroxene — Sittampundi. Analyst: C. E. Nehru.

(2)   Salite from gabbroic anorthosite gneiss, Ausable Quadrangle. Analyst: R. B. Ellestad. Amer. Min. Vol. 35, No. 9. p. 660-661.

The hypothetical metasilicate molecules $CaSiO_3$ $MgSiO_3$ and $FeSiO_3$ for the pyroxene are calculated and plotted in the trilinear
S. 6

coordinate diagram of Hess (1941). The pyroxene falls in the Salite Field and it is interesting to note that the pyroxene (2) of Table II is also salite, according to Hess' (1941) classification of clino-pyroxenes.

The Niggli values for the pyroxene are as follows :—
kp — 1·65 Cal — 10·42 Fo — 27·73   Fa — 7·61   Q — 14.17
Ne—5·29 Cs —31·03 Fs— 1·82 Ru — 0·28
          Q — 14·17, L — 17·36, M — 68·47

When the Q, L, M values are plotted in Niggli's diagram (1945) the point falls just outside the field of pyroxenes of igneous rocks.
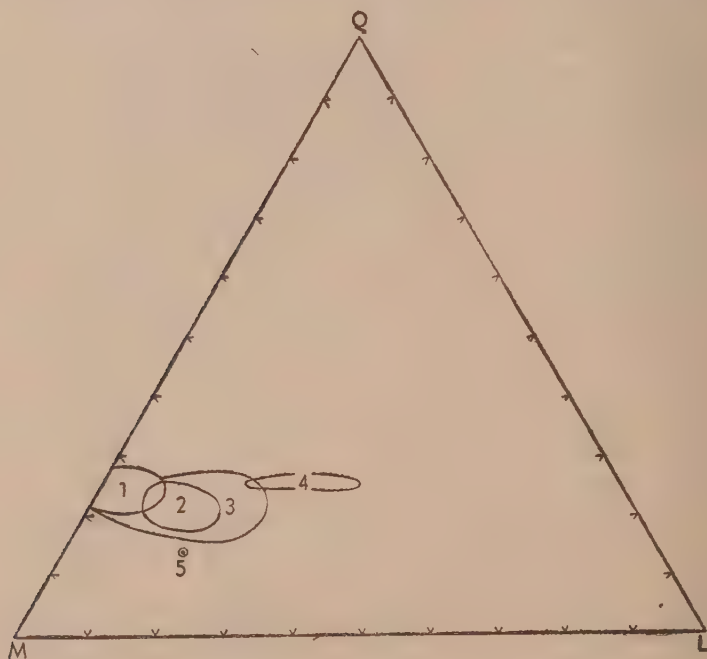
Fig. 1:   Niggli's Q, L, M diagram for pyroxenes.

1. Orthoaugite, pigeonite, and diopside; 2. Common augite; 3. Pyro-xene field; 4. Omphacite; 5. Pyroxene from Sittampundi.

Optical Characters :—

The optic axial angle and the extinction angle are got by pro-jection of the optical constants on a stereogram. The average of five determinations of the optic axial angle (by projection) is+60°.
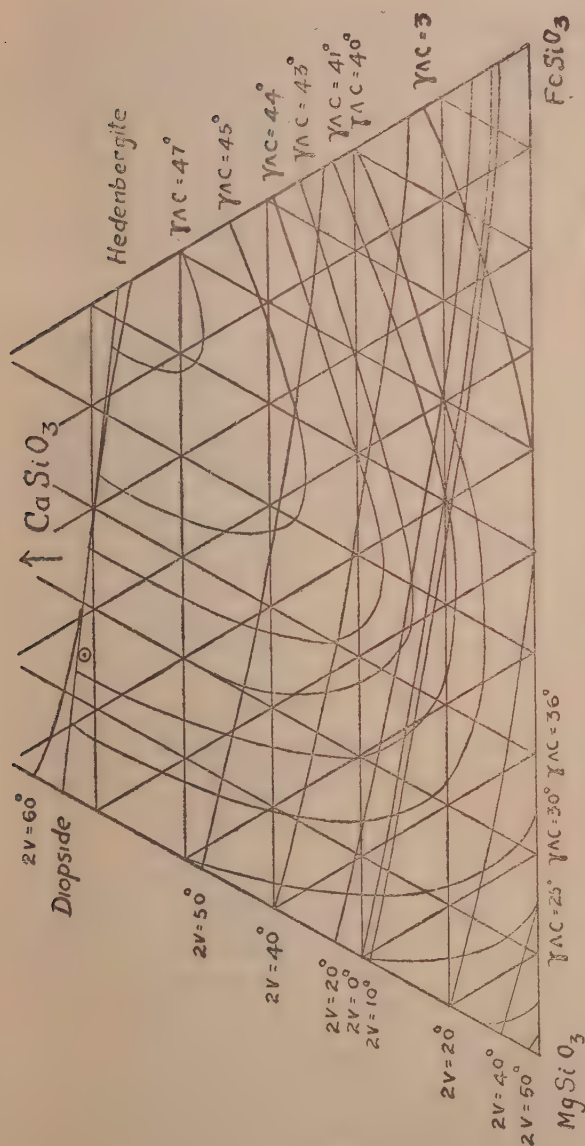
FIG. 2. Diagram connecting the composition and the optical properties of clino-pyroxenes from Deer and Wager (1938) after Tomita (1934). ⊙ Pyroxene from Sittampundi.

The average of four determinations of the extinction angle ZΛC (by projection) is 42°.

The diagram of Wager and Deer (1938) after Tomita (1934) connecting the optic axial angle, extinction angle and the chemical composition of clinopyroxenes is reproduced in Fig. 2. The optic axial angle, and the extinction angle for the composition of the analysed pyroxene are read on the diagram and the values are found to agree closely with the determined optical data.

Conclusion : —Looking at the chemical composition of the pyroxene it is obvious that it has crystallized from a magma rich in alumina and calcium.

Buddington (1939) concluded from the field evidence that the anorthosite series was derived from a magma about equivalent to 85% of labradorite, 10% of pyroxene and 5% of accessory minerals with substantial quantity of volatiles. The modal analyses of the garnet — pyroxene rock in which the pyroxene occurs as a local concentration is given below.* The mode does not contain free plagioclase and hence it can be concluded that the Sittampundi pyroxene has crystallized from a magma which is poor in plagioclase in contrast with the pyroxene of the Adirondack area.

* Approximate Mode of Garnet Pyroxene Rock.
Garnet — 47·5%; Pyroxene — 38·0%; Reaction Rim — 4·0%.

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Geology and Petrochemistry of the Anorthite Gneiss and Associated Rocks of Sittampundi, Salem District

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ABSTRACT

The anorthite gneiss and the associated rocks of Sittampundi (Salem District) have been chemically analysed and they are compared to similar rocks occurring in the calc-bands of Sankaridrug. These two bands together form an anticline warped up by the intrusion of the granites of the area. The origin of the anorthite gneiss is considered not similar to those of anorthosites occurring elsewhere. The view is put forward that the anorthite complex of Sittampundi represents a metamorphic facies of the eclogite, and pyroxene-hornfels (subfacies—spinel—diopside—anorthite—grossularite subfacies) grades. Original impure calcareous (non-magnesian) sediments and pyroxenite—peridotite intrusions are the units metamorphosed.

Introduction : —Anorthosites have been reported from different parts of the world of which the occurrences in Adirondack. Pigeon-Point—Minnessota, San Gabriel mts. Laramine mts.— Wyoming and in Bengal — India may be mentioned. The anorthosites and associated rocks of Adirondack have been worked in great detail by Buddington (1939), Balk (1930) and others. The rocks occupy an almost unbroken area of 1,200 square miles with various smaller outcrops. The anorthosites of this place are younger than the Granville granite and older than the syenite-granite series, there being many dykes of granite and syenite in the anorthosite rocks. The anorthosites grade into rocks of gabbroic composition. In the Laramine mts. where (according to Fowler, 1930), the anorthosites occupy an area of several hundred square miles, they have been intruded as a true magma into a series of highly folded precambrian schists in the form of a cone shaped mass with thin edges in the upper portion. Gabbro masses rich in magnetite occur in the anorthosites as xenoliths and these grade into

anorthosites.   Granite almost completely surrounds the anortho-
site   and   has   intruded   into   the   latter,   there   being   no
transition   rock.   Miller   (1931)   reports   the   anorthosites   of
Los   Angeles   as   older   than   the   rocks   of   that   region—namely
metasedimentary rocks, metadiorites and granite, the first two hav-
ing been more or less intricately cut and injected by the granite.
All these rocks belong to Paleozoic or Cambrian age.   Chatterjee
(1929) who worked on the anorthosites of Bengal writes that in an
area of about four sq. miles the anorthosite, with gradations into
the gabbroic and dioritic facies, is cut by noritic dykes and the
combination is cut by dykes of distinctly later granite.   Grout
(1928) who studied the anorthosites of Pigeon Point—Minnessota,
conceives the anorthosite body as a great sill intruded into the
granitic rocks of that area.

   Map and Structure :   A study of the rocks of the Sittam-
pundi area is here presented.   A part of the area has been mapped
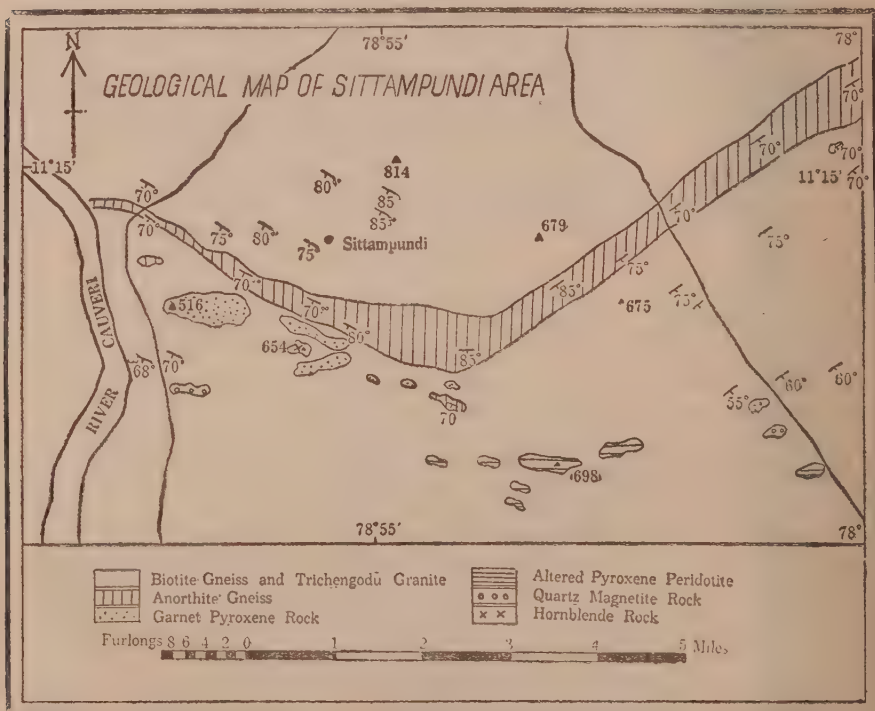
MAP 1

by Aiyengar (1949) of the Geological Survey of India in con-
nection with the study of the chromite deposits of that area.

The present author has mapped the major outcrops found in the area, in general. (Map 1). The area under study extends between Long. 77° 53′—78° and Lat. 11° 12′— 11° 16′. It extends on the northern side upto Sullipalaiyam, on the south upto Sirapalli, on the east upto Karungalpatti and on the west upto Ilamballi and Cholasiramani on the eastern banks of the river Cauveri. The exposures for the most part are surficial except for a few hillocks. The important rock types of the area are the Biotite-gneiss, the Trichengodu-granite, the anorthite-gneiss, the garnet-pyroxene rocks—eclogites, peridotite and quartz-magnetite rock.

The Trichengodu granite is seen as intrusive patches into the biotite gneiss and the anorthite gneiss of the area. The country rock consists of biotite gneiss into which the other rocks like peridotites, eclogites, pyroxenites and possibly anorthosites were intruded. The anorthite gneiss forms a prominent band with a curve which has its convexity towards south, in the middle of the area. The strike and dip of the rocks of this area are of interest. On the western side the strike is nearly NW-SE which gradually changes on to E-W in the middle of the area, and then on to NE-SW on the eastern side. The dips are generally constant at an angle of about 70°-80° towards south. Adjoining the anorthite gneiss on the southern side, are a series of rocks composed chiefly of garnet and pyroxene or hornblende which may be called eclogites. They occur as small hillocks extending from west to east. They sometimes locally grade into pyroxenites and sometimes to pure amphibole rocks. The major outcrops of these rocks are found in the western half of the area though one or two smaller outcrops are also seen at the eastern extreme. Still south of these eclogites are a series of highly altered pyroxene-peridotites which also extend from west to east. The olivine and pyroxene of this rock is highly altered giving rise to serpentine. Magnesite veins of local economic importance are also present in these rocks. The quartz magnetite rock is found as two detached outcrops one on the western border near Ilamballi and the other on the eastern border near Mettupalaiyam village. In the latter exposure the iron ore has altered to haematite.

The Sankaridrug area about seven miles north of Trichengodu proper has recently been studied by my colleague M. N. Balasubrahmanian. With his kind permission I now proceed to mention the following points. The outcrops of the Calc-silicate rocks of Sankaridrug area in general are also crescentic in shape with the convexity roughly pointing towards north. The strike of that area

gradually changes from E-W to NW-SE from west to east. The dips are all towards the northern side roughly about 60°.

A combined study of the maps of the two areas suggests that the rocks of the Sankaridrug area may be the counterparts of the southern suite of rocks Sittampundi. The area in between the two outcrops which are about twenty miles apart consists mainly of the Trichengodu granite which intrudes into the country rock biotite gneiss. A rough sketch of the two areas with the gap in between is given in map 2, on a smaller scale. The distance in bet-


MAP 2

Sketch Map of Sankaridurg and Sittampundi Areas, Salem Dt.

ween the two wavy lines in the map is about fifteen miles. The sketch suggests a quaquaversal fold with the Trichengodu granite mass intruding into the country rocks in the middle and tilting them in all directions away from the centre. To bring out the structure more clearly an idealistic section across the two maps

(roughly from north to south) is taken. In this can be clearly seen the beds of the two areas dipping in opposite directions with the intruded granitic mass in the middle. The ultrabasic rocks of the southern area may be thought of as minor intrusions into the rocks of the area.
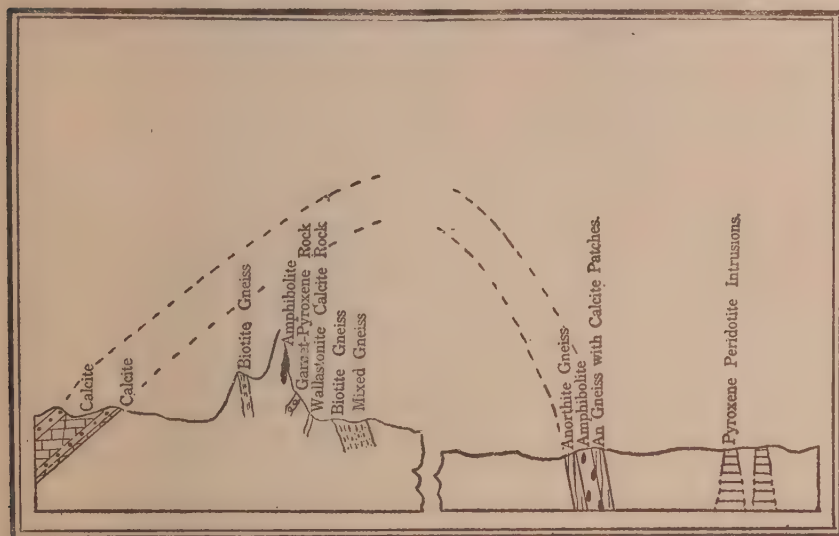
An Ideal Section of the Calc Bands of Sankaridrug and Anorthite Gneiss
of Sittampundi, Salem Dt.
Scale: Vertical 2000′ = 1″; Horizontal 2 miles = 1″

Rock Types :—The anorthite gneiss is light coloured and has a gneissose structure in the hand specimen. The chief mineral constituents are anorthite and blue-green hornblende. Minerals belonging to the garnet, epidote, olivine and spinel families occur as accessories. The approximate volumetric mineral composition of a rock from these anorthite gneisses is computed on a Shand's six spindle micrometer and the results are given below :

N-57.   Anorthite gneiss.

Anorthite	..	83·2%
Hornblende	..	7·5%
Epidote	..	9·3%

Hornblende occurs as elongated prisms arranged with their longer axes roughly parallel to the foliation of the rock. In some places the hornblende and in others the anorthite makes up nearly

S. 7

the whole rock. Two important minerals of economic interest also occur in this rock. Corundum occurs as individual crystals, which are often six-sided and some times eight-sided, in the anorthite gneiss. The concentration of corundum is in the convex part of the band of anorthite gneiss. The other mineral chromite is more distributed in the eastern part of the band of which a detailed account has already been published by Aiyengar. Chromite usually occurs within the amphibolite patches of the anorthite gneiss. Small patches of calcite have also been seen from the anorthite gneiss band in the corundum mines area.

The anorthite gneiss in thin sections exhibits a granulitic texture. The mineral anorthite for the most part is untwinned and exhibits good cleavages. In the hand specimen the colour of the felspar is uniformly white, whereas in the other anorthosite areas like Adirondack and Los Angeles the plagioclase felspar has been mentioned to be of two types—one white and the other blue. Though the plagioclase felspars of the Adirondack anorthosites range from andesine to labradorite, the average composition of the plagioclase is roughly equivalent to labradorite. In the Los Angeles County where also the plagioclase felspars are of white and bluish grey colours the former is found to be always more acidic than the latter, though in general the composition ranges from oligoclase to labradorite.

The plagioclase felspar of the anorthite gneiss of Sittampundi area, on the other hand, ranges from An_{80} to An_{100} in composition and hence, is unusual, and cannot be compared with the anorthosites of the other areas. The major part of the plagioclases are of composition An_{90} to An_{100}.

The biotite gneisses for the most part are prominent through-out the area and the rock exhibits a gneissose structure with intricate folds now and then. The anorthite content of the plagioclase felspar ranges from An_{20} to An_{30}. Garnetiferous phases of this rock are met with in places like Sullipalaiyam. The average volumetric mineral composition of a rock specimen from these gneisses is given below.

N—75. Biotite gneiss

Quartz	.. 45·0%
Felspar	.. 42·5%
Biotite	.'. 12·3%
Accessories	.. 0·2%

Patches of calcite are observed in one or two places in the biotite gneisses also. Reaction rocks have been collected by the author. Calcite, scapolite, pyroxene, epidote and sphene have been identified in thin sections. The approximate volumetric mineral composition of the rock is as follows.

N—37. Reaction rock

Calcite	..	8%
Scapolite	..	26%
Quartz	..	37%
Pyroxene	..	20%
Accessories		
(Sphene and Epidote)	..	9%

Biotite gneisses sometimes show a migmatitic phase when the Trichengodu granite intrudes into them. The approximate volumetric mineral composition of one of the rocks of this type is given below.

N—1. Migmatite

Quartz	..	56%
Felspar	..	20%
Hornblende and Pyroxene	..	15%
Accessories	..	9%

The Trichengodu granite is a coarse pegmatite and is reddish in colour. It is chiefly composed of perthitic microcline and quartz intergrown with each other. No plagioclase felspar is found. Small books of mica are met with in the more coarser varieties and in one place hornblende also occurs. Thus it can well be called Trichengodu pegmatite. The rock which is composed of only perthite and hornblende with very little quartz can be called as an alkali—syenite. This is one of the phases of the Trichengodu granite. The approximate volumetric mineral composition of this rock is as follows.

N—80. Alkali syenite

Microcline	..	89·0%
Hornblende	..	9·5%
Quartz	..	1·5%

The garnet—pyroxene rocks or eclogites consist chiefly of the two minerals garnet and pyroxene. Sometimes plagioclase is also found when the rock grades into a garnet pyroxene diorite. Magnetite occurs as an accessory. The pyroxene is found to be a variety of diopside and the plagioclase ranges in composition from An_{30} to An_{70}. The garnets are rounded and are invariably surrounded by a reaction rim consisting of small elongated patches of plagioclase and hornblende perpendicular to the edge of the garnet. The pyroxene is often seen to have suffered uralitization giving rise to a brown hornblende which sometimes predominates over the pyroxene giving rise to garnet-amphibole rocks. Locally the garnet-pyroxene rocks grade into pyroxenites (wherein an orthorhombic pyroxene also appears) and hornblendites.

The approximate volumetric mineral composition of two of the rocks, one garnet-pyroxene rock and the other a pyroxenite are given below.

N—2.   Garnet-pyroxene rock or Eclogite

Garnet	.. 47·5%
Pyroxene	.. 38·0%
Reaction rim	.. 14·5%

N—98.   Pyroxenite

Pyroxene	.. 79%
Hypersthene	.. 17%
Magnetite	.. 4%

The pyroxene-peridotite rocks are highly altered rocks containing chiefly olivine, pyroxene and their alteration product serpentine. Hornblende and magnetite occur as accessories. The approximate volumetric composition of a rock collected from the above group of rocks is given below.

N—4.   Pyroxene-peridotite

Serpentine	.. 59·0%
Olivine	.. 16·0%
Pyroxene	.. 16·5%
Amphibole	.. 6·5%
Magnetite	.. 2·0%

The quartz-magnetite rock is a dark looking massive rock consisting of a mosaic of quartz and magnetite grains. In the eastern

exposure the magnetite is altered to haematite. The approximate volumetric mineral composition of a specimen collected from the western outcrop is given below.

N—94.   Quartz-magnetite rock

| Quartz | .. | 57·5% |
| Magnetite | .. | 42·5% |

The chemical analyses of nine of the important rock types of the area are given in Table I. The C. I. P. W. norm and the Niggli values are given in Tables II, III and IV.

The H_2O^+ percentage of the Reaction rock (N—37) includes the percentage of CO_2 also, which was not determined separately and hence the norm could not be calculated. In the case of the pyroxene-peridotite (N—4) the silica percentage is so low that the analysis could not be calculated according to the C.I.P.W. rules. The chemical analyses are compared with similar ones in literature from Adirondack anorthosite and associated rock types. It is seen that the three chemical analyses of the biotite gneiss (N—75) the Migmatite (N—1) and the Hornblende alkali syenite (N—80) can be broadly compared with the analysis 19-A of Buddington (1952) of a Hornblende granite pegmatite which occurs as a vein in the quartz syenite gneiss of Adirondack. The analyses of the reaction rock and quartz-magnetite rock could not be compared with any published analyses.

The average chemical analysis of the anorthosites of the Adirondack given by Buddington (1939) is reproduced here in Table I for comparison with the analysis of the Anorthite gneiss of Sittampundi. It can be seen that in the anorthosite the silica percentage is high and the CaO percentage correspondingly low in contrast with the analysis of the anorthite gneiss where the silica percentage is low and the CaO percentage correspondingly high, indicating that the plagioclase of the anorthite gneiss is more calcic than that of the anorthosite, which is actually the case.

Origin:—The various hypotheses put forth by different authors for the origin of anorthosites have been well summarized by Turner and Verhoogen (1951). Workers like Bowen (1917) Balk (1930), Miller (1931) and others believe in the gravitational settling of the plagioclase crystals and the composition of the parent magma has been variously considered to have been gabbroic, dioritic or grano-dioritic.

TABLE I

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
SiO_2	67·96	69·56	61·96	57·23	44·57	41·88	49·68	41·36	29·99	69·87	54·54
Al_2O_3	16·14	13·34	15·17	10·88	26·34	24·52	36·13	7·72	4·10	14·58	25·61
TiO_2	0·19	0·24	0·19	0·51	0·27	0·27	..	0·40	0·10	0·24	0·67
Fe_2O_3	1·69	2·06	1·30	1·17	2·92	..	2·49	1·09	4·08	0·56	1·00
FeO	1·47	1·65	1·63	2·17	0·69	7·77	8·88	11·80	5·76	1·80	1·26
MnO	0·03	0·06	0·09	0·04	0·02	0·28	0·05	0·22	0·14	0·04	..
MgO	1·30	1·48	1·52	3·07	0·91	11·21	1·13	24·62	27·39	0·57	1·03
CaO	4·09	4·63	5·82	14·76	21·45	13·23	0·79	9·95	14·06	1·69	9·92
Na_2O	5·06	4·33	5·97	4·00	2·26	0·12	Tr.	0·41	1·30	2·52	4·58
K_2O	1·30	1·25	5·81	2·20	0·19	0·58	}	0·61	0·39	7·42	1·01
H_2O+	0·21	0·96	0·35	3·81	0·57	0·76	0·57	1·44	11·03	0·11	0·55
H_2O-	0·08	0·06	0·13	0·07	0·17	0·04	0·05	0·05	1·12	0·09	
P_2O_5	..	..	..	..	..	..	..	..	..	0·09	..
Total	99·53	99·62	99·89	99·91	100·36	100·66	99·77	99·67	99·46	99·58	100·17

TABLE II (C.I.P.W. Norm.)

	1	2	3	5	6	7	8
Quartz	22·92	29·16	..	..	..	40·62	..
Orthoclase	7·78	7·78	34·47	1·11	1·67	..	..
Albite	42·97	36·15	38·25	6·29	..	..	..
Anorthite	17·24	13·07	..	60·88	64·50	..	17·51
Nepheline	..	..	3·98	7·10	0·57	..	1·70
Leucite	..	..	..	..	1·31	..	2·62
Corundum	..	..	..	..	..	36·11	..
Sodium Metasilicate	..	..	0·24	..	..	..	..
Acmite	..	..	3·70	..	..	..	..
Calcium Orthosilicate	..	..	..	..	..	..	2·41
Wollastonite	..	..	5·34	18·68	..	..	..
Diopside	1·28	4·06	6·73	0·58	0·46	1·63	9·78
	0·90	2·80	3·80	0·50	0·30	0·20	6·90
	0·26	0·92	2·64	..	0·13	1·58	2·24
Hypersthene	2·40	0·90	..	..	..	2·60	..
	0·66	0·26	..	..	..	12·80	..
Olivine	..	..	..	..	19·46	..	38·22
	..	..	..	..	10·81	..	14·08
Haematite	..	..	..	1·92	..	..	..
Magnetite	2·55	3·02	..	1·39	..	3·71	1·62
Ilmenite	0·46	0·46	0·46	0·61	0·61	..	0·76
Water	0·30	1·02	0·48	0·74	0·80	0·62	1·49
Total	99·72	99·60	100·09	99·80	100·62	99·87	99·33

TABLE III Niggli Values

Niggli Magma Types	1	2	3	4	5	6	7	8	9
	Granodioritische magmen					Pyroxenitische ariégitisch		Pyroxenitische (Koswitisch)	Between Pyroxenitische and peridotische
si	281·1	302·6	211·0	163·3	101·4	79·69	149·7	64·88	42·51
al	39·21	33·94	30·47	18·32	35·20	27·39	64·01	7·06	6·81
fm	18·86	22·98	15·75	21·23	6·96	44·75	33·46	75·06	69·63
c	18·11	21·41	21·26	45·37	52·53	26·95	2·53	16·75	21·43
alk	23·82	21·67	32·52	15·07	5·32	0·91	—	1·13	2·13
k	0·15	0·17	0·39	0·26	0·05	0·75	—	0·50	0·16
mg	0·43	0·42	0·49	0·62	0·10	0·72	0·15	0·77	0·84
π	0·24	0·22	—	0·10	0·74	0·94	1·0	0·73	0·23
γ	0·13	0·28	0·58	0·67	0·76	0·01	—	0·13	0·23
μ	0·37	0·30	0·21	0·21	0·03	0·71	—	0·67	0·65

TABLE IV Niggli Basis

	1	2	3	4	5	6	7	8	9
Kp	4·68	4·78	20·30	7·94	0·67	1·97	—	1·95	1·33
Ne	27·45	23·55	28·49	22·39	12·49	0·66	—	1·95	6·99
Cal	10·37	8·02	—	3·28	36·98	38·12	2·42	10·26	2·50
Sp	—	—	—	—	—	—	4·84	—	—
Hz	—	—	—	—	—	—	21·61	—	—
Ns	—	—	1·64	—	—	—	—	—	—
Cs	0·95	2·95	8·52	21·22	14·02	0·33	—	9·39	19·76
Fo	2·73	3·13	3·11	6·68	0·45	23·00	—	50·14	57·03
Fa	1·79	2·16	1·86	2·71	0·84	9·20	—	13·56	6·83
Fs	1·84	2·22	1·31	1·38	3·04	—	2·77	—	4·33
c	—	—	—	—	—	—	21·56	—	—
Ru	0·17	0·17	0·17	0·35	0·22	0·22	—	0·27	0·06
Q	50·02	53·02	34·60	34·05	31·29	26·50	46·80	11·34	1·17
Q	50·02	53·02	34·60	34·05	31·29	26·50	46·80	11·34	1·17
L	42·50	36·35	50·43	33·61	50·14	40·75	2·42	14·16	10·82
M	7·48	10·63	14·97	32·34	18·57	32·75	50·78	74·50	80·01

(1) — N-75 — Biotite Gneiss — Analyst: C. E. Nehru

(2) — N-1 — Migmatite — "

(3) — N-80 — Hornblende alkali syenite — "

(4) — N-37 — Reaction Rock — "

(5) — N-57 — Anorthite gneiss — "

(6) — N-2 — Garnet - pyroxene rock - Eclogite — "

(7) — N-94 — Quartz - magnetite rock — "

(8) — N-98 — Pyroxenite — "

(9) — N-4 — Altered Pyroxene - peridotite — "

(10) — 19-A — Hornblende granite pegmatite occurring in Quartz syenite gneiss—Quary 0·7 miles South of Balfour Pond, New Comb. Quad. — Analyst: H. Badsgaard. A. F. Buddington (1952) Amer. J. Sci. Bowen, Vol. Pp. 66-68.

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Buddington (1939) with particular reference to the anortho-sites of Adirondack advocates that the gabbros, syenites, and granites which are always associated with anorthosites are all of independent origin and post-date the period of anorthosite intru-sion. All these rocks are regarded as derivatives of a parent magma the composition of which would approximate to 80% of labradorite, plus 10% of pyroxene and 5% of accessories with a substantial quantity of volatiles.

The difficulty in applying these theories of magmatic origin to the anorthite gneisses of Sittampundi are: (i) the unusual high anorthite content of the plagioclase felspar—An_{80} to An_{100}; (ii) the absence of gabbroic rocks associated with the anorthite gneiss and (iii) the presence of granulitic texture.

On the other hand, the occurrence of the following rock types in the area are of interest—namely calcite patches (non-magnesian) corundum patches, chromite bands with amphibolites, and amphi-bole with anorthite in preference to pyroxene. There are also several xenoliths in the Trichengodu granite which pass off into migmatites containing calcite.

Krishnan (1951) dealing with the Corundum areas of Salem writes as follows:—"The anorthite gneiss and associated rocks may be of igneous origin, but metamorphosed later and subjected to hydrothermal alteration. It is thought that he corundum and the closely associated calcite may have been derived from the anor-thite by the action of CO_2 and water vapour, while the silica formed during the reaction may have been carried away in solution."

It is of interest to note that my colleague M. N. Balasubrah-manian has noted continuous calc bands extending from west to east to the north of Sankaridrug in which he has noted abundant development of scapolite and wollastonite. Similarly scapolite-bearing rocks have been found in Sittampundi. Considering the two occurrences together, the author is of opinion that the cal-cite of the anorthite gneiss of Sittampundi is an original calcareous band recrystallized but unreacted upon by the granite magma. The development of anorthite, spinel, diopside, and garnet in the anorthite gneiss recalls the spinel-diopside-anorthite-grossularite subfacies of the pyroxene-hornfels facies of Eskola. Here in Sittampundi one seems to encounter a metamorphic facies in the association together of eclogites, amphibolites, and anorthite spinel

rocks, rather than gabbroic rocks and anorthosites. **Further work is in progress.**

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The Primary Film as a Factor in Settlement of Marine Foulers

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ABSTRACT

(i)   Previous work on the formation of a primary film on sub-merged surfaces and its being a pre-requisite for the settlement of larvae of sessile organisms is reviewed.

(ii)   The formation of the primary film requires 48 hours and larvae settle on the surface only after this period. The larvae do not settle on any surface which is not covered by a primary film. Depend-ing as it does on the growth and multiplication of bacteria, diatoms and algal spores the process of formation cannot be hastened by increasing the concentration of these constituents.

(iii)   The primary film is composed mainly of 34 species of diatoms and 14 species of algae and of a smaller proportion of bacteria.

(iv)   From the results of the experiment it will be clear that of the three constituents of the primary film the bacteria are the least important. It is not quite clear in what way the diatoms and algal spores of the primary film induce the settlement of the cyprids.

INTRODUCTION

Of the several factors which induce the settlement of fouling organisms, the formation of a primary film over underwater sub-strata has been considered by Angst (1923) and Whedon (1937) to be the most important, so far as the majority of the sedentary organisms are concerned. Hilen (1923) and Miller (1946) how-ever, found the larvae of some sedentary organisms attaching themselves to clean or newly submerged surfaces before any visi-ble film is formed. ZoBell (1939), Cole and Knight Jones (1949) as well as Miller working with Whedon and Rapean in 1948 showed that larvae settle more readily on filmed rather than on unfilmed surfaces. It will be obvious that no general rule can be deduced to

cover all animals. The present author found that as far as barnacles are concerned a primary film is a pre-requisite for fouling.

There is no agreement regarding the composition of this primary film and its relation to both non-toxic and toxic surfaces. While ZoBell (1939) and others who studied the primary film in the eastern coast of the United States, found it consisting mainly of bacteria, Wood (1950) who examined the primary film in the subtropical waters of Australia found it mainly of diatoms and algal spores.

Since there is no clear and consistent account of the composition and role of primary film and since fouling has not been studied in the tropics except by Wood 1950, and since fouling is a serious problem in tropical Madras, it was considered worthwhile to study the problem and find (i) whether a primary film is necessary in fouling (ii) the components of the primary film and (iii) whether the diatoms and algal spores are more important than the bacteria of the primary film.

(i)

Since the coating acquired by any clean freshly submerged surface is of living matter and not due to sedimentation of dead matter, the details of the process of its formation, the duration, as well as the physico-chemical factors responsible for it were first studied. The completion of the process was indicated by the attachment and normal metamorphosis of the larvae of *Balanus amphitrite* and *Hydroides norvegica* the dominant members of the fouling community. Glass panels were immersed in selected sites and were examined, and the observations from several experiments are reported here. Salinity, temperature, pH, oxygen content, Nitrite nitrogen, phosphates and silicates of the sea water at the different sites, were estimated throughout the year. But as the experiments were performed only during 11 day periods in each of the months of the year and as the results did not vary from month to month, the data regarding the physico-chemical conditions are not presented here.

Experiment 1 :—The period which has to lapse before larvae settled on panels freshly immersed was observed as follows : Ten smooth glass slides measuring 4″ x 3″ cleaned with chromic acid and washed in tapwater, were immersed one foot below the low-tide at the New North Quay of the Madras harbour, each month from July 1951 to April 1952. Every day the plates were removed to large petridishes and examined with a handlens and put back

GRAPH 1
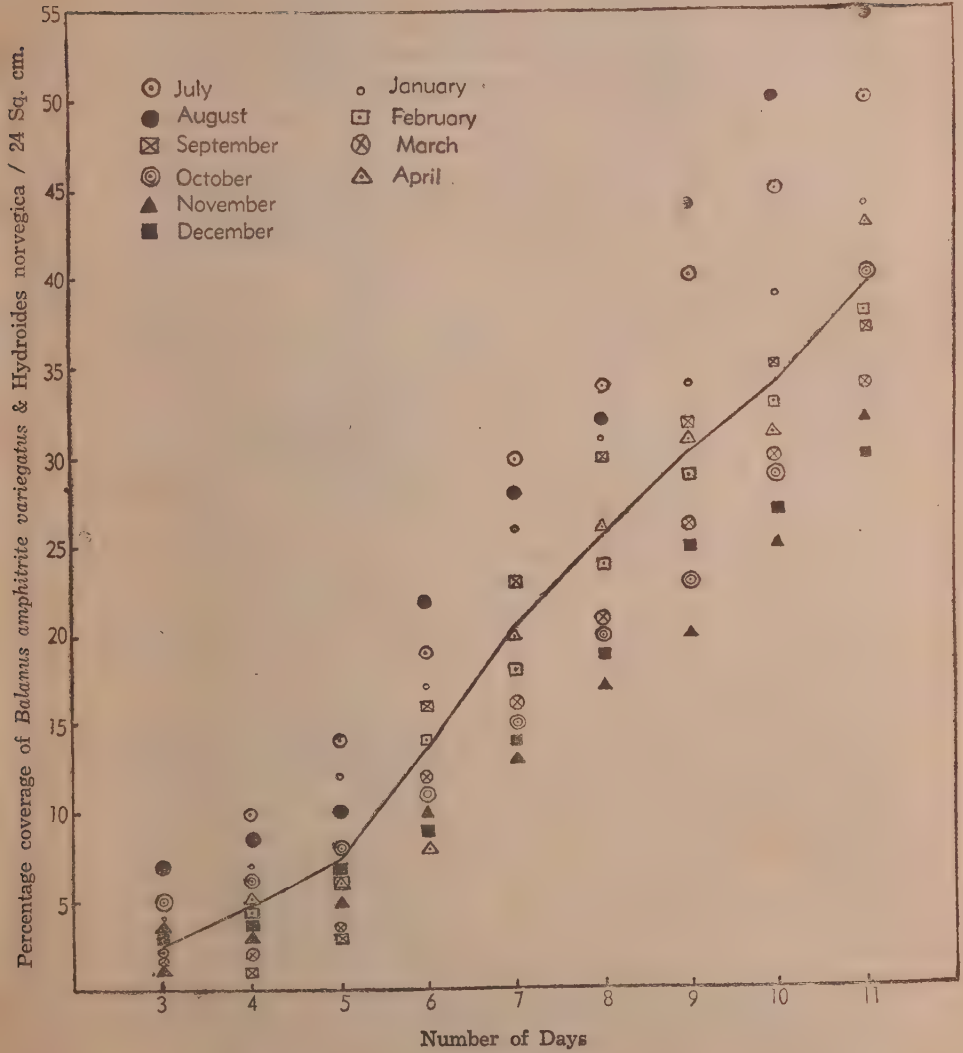
in their former position, in the sea.   It was found that on an average only about eight cyprids were very feebly attached when both the sides of the glass panel (an area of 24 sq. in.) were examined.   Considering the numbers which settled later, it must be assumed that even the larvae of the most successful foulers, *Balanus amphitrite* and *Hydroides norvegica,* failed to settle for the first two days of immersion.

The number of larvae which attached on the third and successive days were counted and the areas covered by *Balanus amphitrite* and *Hydroides norvegica* were measured to gauge the degree of successful settlement.   Since the rate of fouling does not increase appreciably after eleven days, observation was discontinued and the experiment was repeated during each of the next nine months. Data collected from the ten test plates exposed each month were averaged and are plotted in Graph I.   The mean of the ten monthly averages, is indicated by the curve.   It will be seen from the Graph that there was no settlement of larvae during the 48 hours following immersion of the panels during most months.   In September and February, larvae did not settle for 72 hours and the increase during the 11 day period is not so pronounced.   But from the tracing it will be clear that the numbers of larvae settling from 3rd day to the 11th day increased steadily and that the failure to settle during the first two days must be explained as due to the primary film not being formed.

Experiment 2 : —To see whether, if the primary film is already formed, larvae will settle readily on immersion the following procedure was adopted.   Large troughs in the laboratory were filled with sea-water fetched from the harbour.   Ten clean panels were immersed in the water.   After 72 hours the glass panels were found coated with primary film.   They were left in the same site as in the previous experiment.   They were examined every day and the areas covered by cyprids of *B. amphitrite* and larvae of *Hydroides norvegica* in each of the ten plates were measured and averaged. This test was repeated during the ten months.   It was found that the averages were 6·5%, 13·4%, 18·5%, 24·9%, 33·1% 40·8%, 48·4%, 53·6%, 59·4%, 64·3% and 66·5% from the first to the eleventh day respectively.   *B. amphitrite* and *H. norvegica* covering an area of 2% to 11% of the total area exposed even on the first day is significant.   The subsequent increase to 57% to 74% being higher than what was reached in Experiment 1, must be explained as due to a thicker formation of primary film in the laboratory, than in the disturbed waters of the sea.   It may be

therefore inferred that when the primary film is completed, attachment of the larvae takes place forthwith and that the delay of fortyeight hours is only for the formation of the primary film because both in the laboratory and in the harbour there was no lack of larvae and cyprids of *B. amphitrite* and larvae of *H. norvegica.*

Experiment 3 :—To see how cyprids will behave when both cleaned and filmed surfaces are made available together in a limited volume of water and when no filmed surface is offered, the following tests were carried out.

Two large rectangular troughs of about 4½ cu. ft. were filled with sea water. At the end of five days when a film was formed, visible to the naked eye, two sides of one trough (A) were rubbed clean with cotton wool so as to remove the primary film, the other trough (B) was left with the film intact. These two troughs were once again filled with sea water. A third trough (C) of the same size was filled with sea water. The sides of this trough were wiped clean every four hours to prevent the formation of a primary film.

One hundred cyprids larvae which were about to settle were introduced into each trough at about 10 a.m. and the number of cyprids which had settled after 24 hrs. were counted. (Collection of cyprids was easy since they swim near the surface in large numbers and can be townetted.)

In trough C which was cleaned every four hours no larvae settled and all the larvae perished after ten days. In trough B, which served as control, nearly 60 to 84 were found attached in a normal manner in the different sides of the trough. In trough A, however, 79 to 95 of each 100 larvae preferred to attach on filmed surfaces rather than on cleaned surfaces. This experiment was repeated more than 15 times and the results were more or less uniform. When examined with a lens the reactions of the larvae to clean and filmed surfaces in the same trough appeared to be based on deliberate choice. When the larvae approach a clean surface, they just touch the substratum with the antennae, twice or thrice and then swim away very quickly whereas when they reach a filmed surface after a few exploratory touches, they crawl slowly over the substratum and come to a stop.

Experiment 4 :—To see if the formation of the primary film can be accelerated and the initial period of two days shortened the following experiment was conducted in the laboratory. Two large troughs A and B were filled with sea water. Scrapings from films formed on surfaces containing a rich culture of algae, diatoms and

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bacteria were introduced into trough A while in trough B no such addition was made. Microscopical examination of the slides let in both the troughs showed that a primary film developed only by the beginning of the third day in both troughs alike.

Moreover 100 cyprids larvae which were about to settle down introduced at the beginning of the experiment failed to settle in both the troughs A and B, for the first two days. On the third day only about 12 to 14% were found attached, the rest having perished during the first two days. This experiment was performed several times during the year but the results were the same indicating that a primary film is formed only at the end of two days even when a larger bulk of algae were supplied. It is probable that the acceleration of the film formation is not possible because the algal spores take three days to develop and form the algal colonies.

The results of the foregoing experiments can be summarised as follows: — (i) fouling does not commence till after a lapse of a period of 48 hours taken for the formation of the primary film, (ii) plates with primary film already formed facilitate the settlement of the larvae without any delay (iii) the larvae appear to avoid other surfaces by behavioural or structural necessity and would rather perish than attach to a surface without primary film and (iv) the period of 48 hours necessary for the formation of a primary film cannot be reduced by increasing the concentration of the constituents of the primary film, in other words, the fouling of any surface is a biological process, not depending on the concentration of the bacteria, algal spores and diatoms, but on their growth and multiplication in situ.

(ii) *The components of the Primary film in the tropical waters of Madras*

To watch the progress of the formation of the primary film more closely and to estimate the relative proportions of the constituents of the slime film, three stations, A and B inside the harbour and station C outside the harbour were chosen. Eight slides 3″×1″ were immersed and after 1 hour one slide was taken out of the sea and transferred to a jar of filtered sea-water. After the 2nd and 3rd hours two more slides were consecutively transferred and brought to the laboratory, dried, stained with safranin or by Gram's method (Hucker's modification) and examined. In order to comply with statistical requirements (Hanks and James, 1940) 20 fields were counted on each slides, starting from the centre, along two diagonals. The remaining five slides were removed at the end of 24 hours, 48 hours, 3rd day, 4th day and 5th day and were

examined similarly. The approximate number of bacteria, algal spores and diatoms counted in the 20 fields were averaged and the numbers in an area of 1 sq. cm. were calculated. The above observations were repeated at each station, every month from October 1951 to September 1952. But as it was found that the data collected each month did not differ appreciably from those of any of the succeeding months, the tables were consolidated and presented as for one single month in Table I below :

TABLE I

Exposure	Organisms	Count per square centimetre.		
		Station A	Station B	Station C
One hour	Bacteria	590	505	1278
	Diatoms	2752	1414	2630
	Algal spores	3166	3117	3052
Two hours	Bacteria	1546	1348	2094
	Diatoms	2249	1713	1908
	Algal spores	2376	1659	2607
Three hours	Bacteria	1292	1188	2690
	Diatoms	4755	2488	2735
	Algal spores	4684	3164	3065
Twenty-four hours	Bacteria	3955	3261	6619
	Diatoms	4523	4801	5904
	Algal spores	10737	5833	11324
Two days	Bacteria	8322	6358	11900
	Diatoms	11679	9345	10323
	Algal spores	14203	12723	15204
Three days	Bacteria	14843	10162	16192
	Diatoms	19511	17274	17368
	Algal spores	19500	23377	27368
Four days	Bacteria	15885	11785	18928
	Diatoms	19495	12427	22650
	Algal spores	30975	24950	23370
Five days	Bacteria	19328	18886	26436
	Diatoms	30530	36915	44730
	Algal spores	84250	82020	58270

A perusal of this Table will show that the primary film is formed chiefly of diatoms and algal spores with a relatively smaller proportion of bacteria. The primary film is completed (i.e.) ready for settlement of larvae, at the end of 48 hours when the algal spores and diatoms reach a count of 14043 per sq. cm. and 10449 per sq. cm. respectively. It will be obvious that the increase in numbers of diatoms and algal spores, is not always directly proportional to the duration of the immersion period and that bacteria are more in number in Station C outside the harbour. This is undoubtedly due to the drainage of sewage near Station C.

Both gram negative and gram positive groups were recognised among the bacteria. 34 species of diatoms and 14 species of algae were identified* and are listed below: —

DIATOMS

Coscinodisceae: — (1) *Coscinodiscus lineatus* Ehrenberg; (2) *C. concinnus* Smith; (3) *C. radiatus;* (4) *C. excentricus* Ehrenberg; (5) *C. gigas* Ehrenberg; (6) *Planktionella sol* (Wallich); (7) *Thalassiosira candensata* (Cleve).

Biddulphieae: — (8) *Biddulphia sinensis* Greville; (9) *B. mobiliensis* Bailey; (10) *B. regia;* (11) *B. rhombus;* (12) *Ditylum sol* Grunow; (13) *D. brightwelli* (West); (14) *Bellarochea sp;* (15) *Eucampia zodiacus* Ehrenberg.

Fragilarioideae : — (16) *Thalassiothrix nitzschioides* Grunow; (17) *T. longissima* Cleve; (18) *Asterionella bleakleyi;* (20) *Fragilaria oceanica* Cleve.

Solnieae: — (21) *Rhizosolenia calcaravis* Schultze; (22) *R. alata* Brightwell; (23) *R. setigora* Brightwell; (24) *R. robusta;* (25) *R. styliformis* Brightwell; (26) *R. spp;* (27) *Guinardia* spp.

Chaetocereae: — (28 *Bacteriastrum varians* Lauder; (29) *Chatoceras debile;* (30) *C. decipiens;* (31) *C.* spp.

*Nitzschiaceae:* — (32) *Nitzschia seriata* (cleve); (33) *N.* spp; (34) *Bacillaria paradoxa* Gmelin.

Algal Spores of: — (1) *Ulothrix flacca;* (2) *Champia parvula;* (3) *Centroceras clamlatum;* (4) *Oscillatoria priceps* Vauch; (5)

Lyngbya oesturaii (Martens); (6) *Enteromorpha intestinalis;* (7)
Cladophora glomerata; (8) *Polysiphonia sertularioides;* (9) *P.
subtilissma;* (10) *Ceramium elegans;* (11) *Gracilaria lichenoides;*
(12) *G. confervoides;* (13) *Trichodesmium erythraeum;* (14) *T.
thiebauti.*

iii.   *The relative importance of diatoms and algal spores and bacteria*

Though diatoms, algal spores and bacteria constitute the pri-
mary film in the Madras harbour waters the role played by the
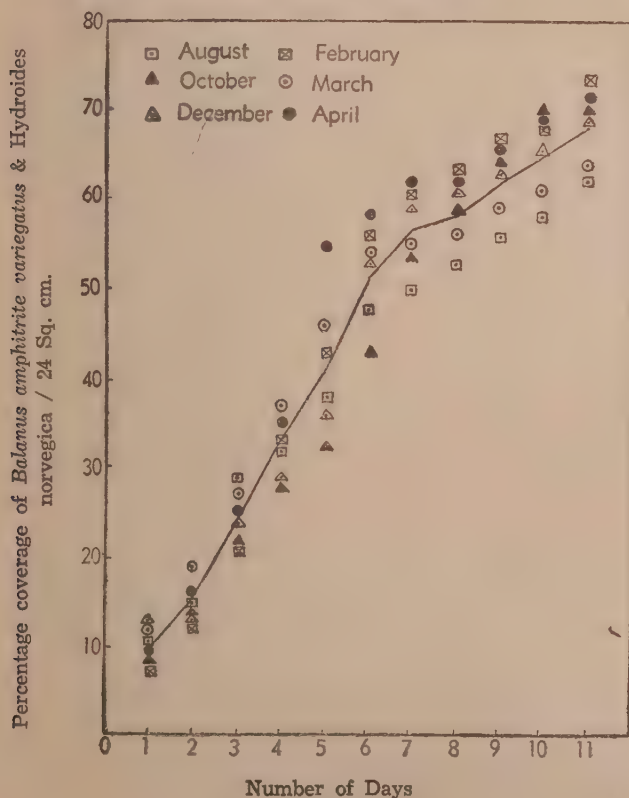
GRAPH 2

bacteria appears negligible although it is difficult to assess quanti-
tatively. The relatively greater importance of algae and diatoms,
however, was determined by the following experiment.

Experiment 5:—Diatoms and algal spores were isolated from scrapings of surface film and were cultured in Drew's medium in petridishes and these were given several changes.   Ten glass plates 4″ × 3″ were left in the culture for three to five days and then immersed at the exposure sites in the Madras harbour.   The areas covered by the settling larvae were measured during the eleven days following immersion.   The data for each day were averaged and calculated as percentages of the total area exposed. This experiment was repeated in August, October and December 1951 and in February, March and April in 1952, and the means of the average for the six months are set forth in graph 2.   It was found that even on the first day of immersion 7% to 13% of the total area exposed was covered by the foulers.   A film formed of bacterial culture on the other hand did not favour fouling to the same extent.   Bacteria isolated from scrapings of primary film were cultured in Agar solution.   Ten plates 4″ × 3″ were left in this and immersed in the harbour as for the algae.   It was found that even though a bacterial film was readily formed, no larva settled for two days.   On the third day however settlement was as poor as 8% i.e., as much as were collected during the first day, when the film was of algal composition.   The slides examined on the third day and successive days revealed the presence of algae and diaotms.   The steady increase of area covered by larvae on the 3rd to the 11th day (8%, 17%, 19%, 24%, 30%, 36%, 43%, 49% and 57%) respectively must be attributed to the formation of algal spores and diatom film rather than to any part played by bacteria.

To see if the slides coated with a bacterial film will favour settlement, when algae and diatoms were excluded, sea water was filtered several times.   A large trough was filled with this sea water and slides coated with bacterial film were immersed in it. Later about 1000 cyprids were counted and introduced.   When the plates were examined during the consecutive 11 days, it was found that not even a single larva was attached to the plates.   Since the bacteria do not appear to facilitate the attachment of the larvae in the absence of algal spores and diatoms it may be assumed that their place in the primary film is of no significance or as little significance as the organic sediment which may settle on any surface submerged in water.   Incidently it was noted that the cyprids of *B. amphitrite* of Madras were able to survive without settling for about eleven days on an average and when removed to another

vessel with glass slides having algal spores and diatoms, were still able to settle within 48 hours.

It is evident from these experiments that a primary coating of algal spores and diatoms is a prerequisite for the attachment of the larvae of the foulers, yet the precise way by which the constituents of the primary film favour their settlement is by no means clear. It is probable: (1) that the algal spores germinate into their filaments and interspersed by diatoms afford living 'holds' on the substratum for the delicate larvae to get attached to, or (2) that the algal filaments are long enough to wind round the fine microscopic setae of arthropod larvae (Cyprids of *Balanus amphitrite* have been observed under the microscope) in such a way as to entangle them and to stimulate the secretion of white adhesive fluids; (3) The algae and diatoms form the food of several larvae principally the older nauplii of barnacles and the larvae of polychaetes. The attraction exercised by the primary film is sustained thus to a greater extent than by a clean surface; (4) Once a few foulers settle, factors responsible for congregation of sessile organisms become operative and settlement progresses by geometric ratio.

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Additivity and Symmetry for Generalised Uniform Structures, and Characterisations of Semi-Uniform Structures

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ABSTRACT

The generalised uniform structures are considered as c-structures and certain additive or symmetric gu structures are associated to each generalised uniform (or gu) structure. The semiuniform (or su) structures with or without the conditions of additivity or symmetry are characterised in terms of semi écart structures. And a problem of immersion for semi groups of a special sort with a su structure in groups of a special sort with symmetric su structure is treated as a generalisation of the immersion of the system of nonnegative real (or rational) numbers in the system of all reals (or rationals).

INTRODUCTION

Here we consider the generalised uniform (or gu) structure as a c-structure in the sense of K1 (see the bibliography) with uniformly continuous mappings as the c—homomorphisms; the gu structure, which is specified by the association of a family of 'surroundings of the diagonal of $M \times M'$ where M is a point set, admits the operations of associating a certain related gu structure which is additive or symmetric respectively. These lead to operators on types of gu structures whose interrelations to other operators defined from the theory of K1 are studied in the first section.

The addition of a (feeble) transitivity condition on the surroundings gives rise to the semi-uniform (or su) structures. Topologically the semi-uniform structure gives nothing more than a v-space (as shown in a note K2 earlier). The characterisation of the su structure as a gu structure is here presented, in terms of su structures defined by semi écarts, which are distance functions satisfying only the triangle inequality in its non-symmetric form. These characterisations follow as corollaries (1 to 5) from the results of K1 applied to the basic structure theorem 2. This struc-

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ture theorem has been proved for the special case of additive, symmetric su structures in Bourbaki's book (B2), and the proof here is exactly similar.

The symmetrising process suggests the generalisation, worked out in section three, of the immersion of the additive semi-group of non-negative real (or rational) numbers, with its su structure specified by the nuclear base of right open intervals containing O, in the group of all reals (or rationals) with its usual symmetric su structure, the immersion being for the algebraic as well as the gu structure. The immersibility algebraically of any commutative semi-group, in which divisibility is a total order, in a totally ordered group in which the order is preserved under translations seems not to have been noted before. That a su structure for the semi-group can also be extended to a symmetric su structure for the group is the generalised result proved in the last section.

An abstract of the results of this paper was read before the twentieth Conference of the Indian Mathematical Society at Hyderabad in December 1954.

1. *The generalised uniform structure and the semi-uniform structure*

(1·1) A set M, whose elements we shall call points, together with a family of subsets $\{U_i\}$, of the product set M $\times$ M, where the index i ranges over an arbitrary indexing set I, is called a *generalised uniform* (or *gu*) *structure*, if the subsets U_i all contain the 'diagonal' subset D (consisting of the pairs (p, p), p ranging over M). This is effectively the definition of I. Konishi, (Ko) only no topology is yet assumed for M. If the family of the U_i is denoted by U, then U is also called the generalised uniformity (or *gu*) of M and the U_i are called the U-surroundings. (M, U) denotes the *gu* structure itself.

If f is a mapping of the set M in the set M', and (M, U), (M' U') are two *gu* structures, then the mapping is said to be a uniformly continuous (or uc) map, from the first to the second gu structure, if to each U_i' from U', there exists a U_i in U, such that $f(U_i)$ is contained in U_i'. If f is a one-one mapping of M on M' and f and f^{-1} are uc maps from the first to the second *gu* structure and vice-versa, we call these maps *unimorphisms*, and the structures are said to be unimorphic.

Before considering examples, we note some of the usual extra conditions on the *gu* **U**, which lead to special types of *gu* structures, (**M**, **U**).

J1:   (Additivity) Given any two **U**-surroundings U_i, U_j there can be found a **U**-surrounding U_k such that it is contained in both U_i and U_j.

J2:   (Symmetry) Given any **U**-surrounding U_i, its inverse U_i^{-1} (consisting of the pairs (p, q) for which the pair (q, p) belongs to U_i) is contained in U_i; and so is identical with it.

J2′:   (feeble symmetry) Given any **U**-surrounding U_i, there can be found a **U**-surrounding U_j whose inverse U_j^{-1} is contained in U_i.

J3:   (Transitivity) Given any **U**-surrounding U_i, the relational product $U_i U_i$ is contained in U_i (the relational product $U_i U_j$ of two subsets U_i, U_j of $M_i M$ being the set of pairs (p, q) of points from M from which a point z can be found in M such that (p, z) is in U_j and (z, q) is in U_i).

J3′:   (Feeble transitivity) Given any **U**-surrounding U_i, there can be found a **U**-surrounding U_j such that $U_j U_j$ is contained in U_i.

We shall call a *gu* structure satisfying the feeble transitivity condition a *semi uniform structure* (or, shortly, a *su structure*).

(1:2)   The first natural example of the *gu* structure is given by the *distance structures* (or *d structures*) which we define as a set M of points together with a non-negative real valued 'distance' function $d(p, q)$ defined for each ordered pair of points (p, q) such that $d(p, p)$ is zero for each p in M. We denote that d structure by (**M**, d). This structure determines an associated *gu* structure (**M**, **U**), where **U** consists of the sets U_c defined for each positive real number c to be the set of pairs (p, q) with $d(p, q)$ less than c. We denote the associated *gu* structure also by (**M**, d), and refer to it as a 'distanciable' gu structure. It is necessarily additive.

The extra conditions usually considered for the distance function $d(p, q)$ defined in M are:

D1: (Symmetry). $d(p, q)$ equals $d(q, p)$, for each pair p, q from M.

D1': (Feeble symmetry)   Given a real positive number c, a real positive number e can be found such that, whatever be the pair of points p, q from M, $d(q, p)$ is less than e implies $d(p, q)$ is less than c.

D2: (Triangularity)   For any three points p, q, r, one has $d(p, r) \leqslant d(p, q) + d(q, r)$.

D2': (Strong triangularity)   For any three points p, q, r from M, $d(p, r) \leqslant$ the maximum of $d(p, q)$ and $d(q, r)$.

We may observe that for the distanciable gu structure (M, d), the conditions D1, D1', D2' and D2 for the function d imply respectively the conditions J2, J2', J3 and J3'.

When D2 is satisfied the distance structure is called a semi écart structure.   D1 and D2 give an écart structure, in the sense of Bourbaki (B2)

(1·3)   The second example of the gu structure is given by the semi-group with a nuclear base; a semi-group is a set S closed for an associative, binary operation (which we take as a multiplication, and denote by.) such that the cancellation laws are true on both sides (for any three elements a, b and c, either $a.c = b.c$, or $c.a = c.b$, implies $a = b$).   We assume further that S possesses a two sided unit element 1; then a family of subsets V_i of S (i ranging over an indexing set I) forms a nuclear base for S if the following are true: every V_i contains 1, and given a V_i a V_j can be found such that V_i contains the (complexes) product $V_j. V_j$. If further every pair of the nuclii V_i contains a nucleus, then the base is said to be additive.   If the semi-group is a group under the multiplication and the base satisfies the condition that each nucleus equals its inverse (consisting of the inverses of its elements) the base will be called symmetric.

Given a semi-group S with a nuclear base $V = \{V_i\}$, the associated su structure (S, V') is defined by taking as V'-surroundings the sets V_i' consisting of the pairs (p, q) from S for which q belongs to $V_i.p$.   It is clear that, under this gu structure, multiplication of the elements of S by a fixed element on the right will be a uniformly continuous operation; in the case when S is a group and the base is symmetric, inversion and left-multiplication by a fixed element are also uniformly continuous operations.

2. *The gu structure as c-structure and the operators of additivity,*
symmetry and feeble symmetry.

(2.1) *Theorem 1.* The *gu* structures considered as c-structures, with arbitrary sets as b-structures, and *uc* mappings and set mappings taken as the c- and b-homomorphisms respectively satisfy the axioms A1 to A7. Similarly the additive *gu* structures satisfy the same axioms, the b-structures and the b- and c-homomorphisms being as before.

Proof. The axioms A1 to A6 require only a routine verification. For A7, the two cases above require the use of two different forms of product structures. For a class (M_n, U_n) of *gu* structures the two forms of product, the coarse one $P'\{(M_n, U_n)\}$ and the fine one $P\{(M_n, U_n)\}$ are both defined over the cartesian product set $M = P(M_n)$, the *gu* U' for the first consisting of the product sets of the form $P\{A_n\}$ where all but one of the A_n's equals M_n for the same n, while that single A_n alone is a U_n-surrounding arbitrarily chosen; the *gu* for the second product is U, consisting of all finite intersections of the U'-surroundings already defined. It is the coarse product which has to be taken for verifying A7 when the c-structures are arbitrary *gu* structures, while the fine product is to be used when the c-structures are restricted to the additive *gu* structures.

We may further remark that there are corresponding differences in the definitions of the operators Π, l, for these two types of c-structures; the coarse ones Π', l' corresponding to the case of arbitrary *gu* structures and the fine ones Π, l to the case of the additive *gu* structures. For a family (M, U_n) of comparable *gu* structures the coarse lattice product (M, U') consists in taking U' to be the union of the U_n, while the fine lattice product (M, U) is given by taking U to consist of all finite intersections of the sets in U' defined above. Similarly for an inverse directed system the difference between l' and l arises from whether the product *gu* is the coarse or the fine one. The lattice of structures comparable with a given one, are in these cases complete lattices with all sums distributive; even all products are distributive for the case of the arbitrary *gu* structures.

(2.2) The above view of *gu*, or additive *gu*, structures, as c-structures leads us to the definitions of the operators on types (as described in K1) i, s, d, h, P, p, Π, π, l, and P′, p', Π', π', l', the last five not necessarily leading to additive *gu*'s even when

applied to additive ones.   Corresponding to the conditions of additivity, symmetry and feeble symmetry defined for gu structures we now associate to each gu structure an associate which satisfies one of these conditions.   Let (M, **U**) be the (arbitrarily) given gu structure.   Then the *additive associate* A (M, **U**) = (M, **U**′), the *symmetric associate* S (M, **U**) = M, **V**), and the *feebly symmetric associate* S* (M, **U**) = (M, **U***) are defined by taking (i) **U**′ to be the family of finite intersections of the **U**-surroundings, (ii) **V** to be the family of subsets of M × M of the form $U_i \cap U_i^{-1}$, for the U_i taken from **U**, and (iii) **U*** to be the family of the U_i from **U** as also the U_i^{-1}. As these associating functions A, S, S* can also be treated as operators on types of gu structures, we have now to consider further interrelations between combinations of these and the other operators already mentioned.   The results in the following lemma are all easy of verification and so are stated without proof:

Lemma 1. (i)   All three operators A, S, S* are closure operators and permute with each of the operators i, s, d, and h.

(ii)   The operator A permutes with P, p, Π, π, and l; while if φ, φ′ denote respectfully any one of these fine operators and the associated coarse one, then A φ′ is the same as φ; hence A φ′A is identical with A φ′; the operator A also permutes with S;

(iii)   S and S* both permute with each of P′, p', Π′, π', and l', and S permutes with also P, p, Π, π and l; S S* is S*, and S* S is S.

(iv)   A (M, **U**) is the coarsest among the additive gu structures finer than (M, **U**); S (M, **U**) is the coarsest among the symmetric gu structures finer than (M, **U**); and S* (M, **U**) is the coarsest among the feebly symmetric gu structures finer than (M, **U**).

(2.3)   We mentioned already that the distanciable gu structures are necessarily additive, and so the operator A for such a structure gives nothing new.   To see the effect of the symmetry operators S and S*, let us first define to each distanciable gu structure (M, d) a complementary distanciable structure (M, d') by setting $d'(p, q)$ equal to $d(q, p)$, for all p, q from M.   Then the feebly symmetric associate S* (M, d) is the coarse lattice product (π') of the two distanciable gu structures (M, d) and its complement (M, d').   This may not be distanciable.   But the symmetric associate S (M, d) is evidently the distanciable gu structure (M,

d''), where $d''(p, q)$ is the maximum of $d(p, q)$ and $d'(p, q)$ for each pair p, q. Evidently d'' satisfies the symmetry condition, and further if d satisfies either of the triangularity conditions D2, D2' so does d''.

3. The semi uniform structures in terms of the semi écart structures

(3.1)   *Theorem* 2. (a) Any semi uniform structure is the (coarse) lattice product of a class of comparable semi écart structures.

(b)   Any additive semi uniform structure is the (fine) lattice product of a class of comparable semi écart structures.

Proof. If (M, U) is the given semi uniform structure, then starting with any surrounding $U = U_o$ of the diagonal, let us consider a sequence U_i of U-surroundings such that U^3_{i+1} is contained in U_i, for $i = 0, 1, 2, \ldots$. Then a semi écart $f(p, q)$ can be defined on M in terms of this sequence as follows : first $g(p, q)$ is defined for any pair of points p, q of M (i) to be $1/2^k$ if (p, q) is in U_k but not in U_{k+1}, (ii) to be 0 if (p, q) is in all the U_i of the sequence, and (iii) to be 1 if (p, q) is outside U_o even. Then $f(p, q)$ is taken as the lower bound of the finite sums of the form $\Sigma g(z_j, z_{j+1})$ for all possible finite chains of points $p = z_0, z_1, \ldots, z_n = q$, connecting p with q. Evidently $f(p, q)$ is a semi-écart, and $f(p, q) \leqslant g(p, q)$. To prove $f(p, q) \geqslant 1/2\ g(p, q)$, it is enough to show that for any finite chain of z's from p to q, the sum $\Sigma g(z_j, z_{j+1})$ exceeds $1/2\ g(p, q)$. The result being obvious for a one chain, we use induction on the length n of the chain; assuming it for m-chains with $m < n$, let $z_j\ j = 0, 1, \ldots, n$, be a n-chain from p to q, and the sum of the $g(z_j, z_{j+1})$ be c. If $c \geqslant 1/2$, the result to be proved follows from the fact that $g(p, q) \leqslant 1$ always. Let then $c < 1/2$. If the integer h be so chosen that the sum $\Sigma g(z_j, z_{j+1})$, $j = 0, \ldots h$, is less than or equal to $c/2$, while the sum to the index $h + 1$ exceeds $c/2$, then the sum for $j = h + 1, \ldots n$ is also $\leqslant c/2$. As n may be taken $\geqslant 2$, the induction assumption gives $1/2\ g(p, z_h) \leqslant \Sigma g(z_j, z_{j+1})$, $j = 0, \ldots h$,

$$1/2\ g(z_{h+1}, q) \leqslant \Sigma g(z_j, z_{j+1}), \ j = h + 1, \ldots, n$$

so that, since these two sums are each less than or equal to $c/2$, $g(p, z_h)$ and $g(z_{h+1}, q)$ are each less than or equal to $1/2^t$, the greatest number of the form $1/2^m$ not exceeding c,; as $c < 1/2$, $t \geqslant 2$, . Further $g(z_h, z_{h+1})$ being less than c is also less than or

equal to $1/2^t$. Thus (p, z_h), (z_h, z_{h+1}) and (z_{h+1}, q) are all in U_t so that $(p. q)$ is in $U_t{}^3$ hence in U_{t-1}; thus $g(p, q) \leqslant 1/2^{t-1} < 2c$, as $1/2^t < c$. Thus the induction proof is complete. From the result that, for any p, q,

$1/2 \ g(p, q) \leqslant f(p, q) \leqslant g(p, q)$, follows that the su structure for M defined by the family of the surroundings U_o, U_1, $U_2, \ldots$ is the same as the semi-uniform structure defined by the semi écart $f(p, q)$. By well ordering the U-surroundings we can find a family of such sequences U_{i0}, $U_{i1}, \ldots$ $U_{in} \ldots$ such that all the U-surroundings occur among these sequences. Hence there will be determined a family of semi écarts such that the semi uniformities determined by these have U for their (coarse) lattice product. If the original su structure U were additive it would be the fine lattice product of these associated semi écart structures. Thus the theorem is proved completely.

(3.2)   Using the main structure theorem of K1 (thm. 3) we can deduce various corollaries to the theorem 2. Let us first observe that the operators i, s, d, and h lead from semi *écart* structures to semi écart structures only.

Corollary 1.   Among gu structures the su structure may be characterised by each of the following equivalent properties :

(a)   It is the coarse lattice product of semi écart structures;

(b)   it is submersible (i.e., is the dilation of a substructure of) a coarse product of semi écart structures;

(c)   it is unimorphic with a substructure of a coarse product of semi écart structures;

These three correspond to the equivalent closure operators $\Pi'h$, h. P', and $i.s.P'.h$ applied to the gu structure type 'the semi écart structure'.

Corollary 2.   Among gu structures the symmetric su structures are characterised by each of the following equivalent conditions :

(a)   it is the coarse lattice product of a class of symmetric semi écart structures;

(b)   it is submersible in a coarse product of symmetric semi écart structures;

(c)   it is unimorphic with a substructure of a coarse product of symmetric semi écart structures.

These results follow from those of corollary 1, when we observe that the symmetry operator S permutes with Π', p', i, s and h, and that a symmetric su structure is the same as the S-associate of a su structure.

For the next two corollaries, we make use of the fact that the operators π, p (finite fine lattice or direct product operators) give semi écart structures when applied to semi écart structures; one has only to take the sum of the finite number of distance functions involved.

Corollary 3. Among (additive) gu structures the additive su structures are characterised by each of the following equivalent conditions :

(a)   it is the fine lattice product of a class of semi écart structures;

(b)   it is submersible in a fine product of semi écart structures;

(c)   it is unimorphic with a substructure of a fine product of semi écart structures,

(d)   it is unimorphic with the fine limit of an inverse directed class of semi écart structures.

These four results correspond to the equivalent closure operators $\Pi \cdot h$, $h \cdot P$, $i \cdot s \cdot P \cdot h$, and $i \cdot l \cdot \pi \cdot h$ applied to the type of additive gu structure 'the semi écart structure'. The fifth equivalent operator $h \cdot l \cdot p$ or $h \cdot l$ gives a characterisation which is weaker than (d), and so it need not be mentioned. Note that the structure types are equivalent follows from the theorem 3 of K1 when the c structures are taken as the additive gu structures; and that since an additive gu structure can also be characterised as the additive associate of an arbitrary gu structure the condition (a) of this corollary follows from the condition (a) of corollary 1; so these characterisations of the additive su structures may also be viewed as being valid among all (not necessarily additive) gu structures.

Corollary 4. Among (additive) gu structures the symmetric additive su structures can be characterised by each of the following equivalent conditions :

(a)   it is the fine lattice product of a class of symmetric semi écart structures;

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(b)   it is submersible in the fine product of a class of symmetric semi écart structures;

(c)   it is unimorphic with a substructure of a fine product of symmetric semi écart structures;

(d)   it is unimorphic with the fine limit of an inverse directed class of symmetric semi écart structures.

Corollary 5.   The conditions (a) to (d) also characterise the feebly symmetric additive *su* structures among all (additive) *gu* structures.

Corollary 4 follows from the earlier one as the symmetry operator S permutes with *i, s, d, h,* P, *p,* Π & π, and as any symmetric additive *su* structure may be viewed as the symmetric associate of an additive *su* structure.   While Corollary 5 is a consequence of Corollary 4, since any feebly symmetric additive *su* (or *gu*) structure is equivalent (and so equal in the sense of *c*-structure) to a symmetric additive *su* (or *gu*) structure, namely its S-associate.

4.   *The immersion of a semi uniform totally ordered semi group in a symmetric semi uniform ordered group.*

(4.1)   All semi groups and groups considered in this section are multiplicative, commutative and with a unit element 1.

A semi group S is totally ordered if the relation of divisibility "$a \mid b$" (meaning that, for some c in S, ac equals b) is a strict total ordering relation on S (i.e., 1 has no divisor other than itself, and for any a, b either a is a multiple of b, or b a multiple of a).

An ordered group is a group with a total ordering relation $\leqslant$ such that, for any a, b, c from the group, one has $ac \leqslant bc$ (and so $b^{-1} \leqslant a^{-1}$) whenever $a \leqslant b$.

Theorem 3.   (a) The elements containing the unit element 1 in an ordered group form a totally ordered semi group, under the same operation of multiplication.   And conversely, any totally ordered semi group can be imbedded as the system of elements containing 1 in an essentially unique ordered group.

(b)   Any semi uniform totally ordered semi group S, with intervals containing 1 as nucleii, can be imbedded as a sub semi group and sub *su* structure in a symmetric semi

uniform ordered group G, which is determined by S upto isomorphic unimorphisms as an extension of S which can be imbedded in any other similar extension of S. And G has a additive su structure when S has such a one.

Proof. Let G be an ordered group, and S the set of its elements containing 1. Then, with a, b, S contains $a.b$, as $a.b$ contains 1.1 or 1. If a, b are in S and $a \leqslant b$, then $1 \leqslant a \leqslant b$; so $1 = a.a^{-1} \leqslant b.a^{-1}$ so $c = b.a^{-1}$ exists in S with $c.a = b$, or $a \mid b$; conversely, for a, b in S, if $a \mid b$, then there is c in S such that $c.a = b$, or $c = b.a^{-1}$ is in S, and so $1 \leqslant b.a^{-1}$; by multiplying by a, it follows that $a \leqslant b$. Thus the relation $a \mid b$ for elements of S is identical with the total ordering relation $\leqslant$ of G restricted to S. This shows that S is a totally ordered semi group.

Conversely given a totally ordered semi group S, let G consist of S together with a set of elements formally written as a^{-1}, one for each a in S, and with the conventions: $1^{-1} = 1$; $a^{-1} \neq a$ if $a \neq 1$; a^{-1}, b^{-1} are distinct when a, b are distinct elements of S. A multiplication (.) and a ordering relation $\leqslant$ are defined in G thus: for elements of G both in S, the multiplication is as in S; for elements of the form a^{-1}, b^{-1} from G, the product $a^{-1}.b^{-1}$ is defined as $(b.a)^{-1}$; for elements of the form a^{-1}, b the product $a^{-1}.b = b.a^{-1}$ is defined to be the element c of S, or d^{-1} for the d in S, for which it is true that $a.c = b$ or $b.d = a$ (one of which is true in S, by hypothesis). And defining $(b^{-1})^{-1}$ to be the same as b, for each b in S, $a \leqslant b$ is taken to mean $a^{-1}.b$ is in S, for any a, b from G. That G forms a (commutative) group under the multiplication so defined, and that it is an ordered group with $\leqslant$ as the total ordering relation can be verified without much difficulty. Evidently also any ordered group containing S as a sub semi group also contains an isomorph of G as a subgroup with the induced order relation. This means that G is unique upto isomorphism.

b) Let now S be a totally ordered semi group which has a su structure given by a nuclear base $\{V_i\}$ the V_i being intervals ($w.r.t.$ the order) containing 1. As in (a) above let S be immersed algebrically in an ordered group G; a nuclear base for G can be defined by taking the sets $V_i' = V_i \cup S^{-1}$ for the nucleii, where S^{-1} stands for the set of the b^{-1} for the b in S. When V_i contains $V_j.V_j$, then V_i' contains $V_j'.V_j'$ as the latter is just $V_jV_j \cup V_j.S^{-1} \cup S^{-1}.S^{-1} \subset V_jV_j \cup V_j \cup S^{-1} \cup S^{-1}$ and this is contained in $V_i \cup S^{-1}$. Similarly if V_i, V_j contain V_k then V_i',

V_j', contain V_k'. This su structure on G is not symmetric but its symmetric associate is evidently obtained by taking for nuclear base the sets $W_i = V_i' \cap V_i'^{-1} = V_i \cup V_i^{-1}$, the set V_i^{-1} consisting of the c^{-1} for c in V_i. Now the order-symmetric group G with this symmetric su structure contains S not only as a sub semigroup, but also as a sub su structure (for $V_i = S \cap W_i$). And when a order-symmetric group G′ with a symmetric su structure given by a nuclear base $\{W_m'\}$ contains S as a sub semigroup and sub su structure, then identifying the inverse in G′ of each element b of S with b^{-1} in G, G can be imbedded as a subgroup of G′, and it is also a sub su structure; for any V_i must be the same as $W_i' \cap S$ for some nucleus W_i' of G′; whence, since the su is symmetric, $W_i' \cap G$ must equal $V_i \cup V_i^{-1}$; conversely any $W_i' \cap G$ equals $V_i \cup V_i^{-1}$ for a nucleus $V_i = W_i' \cap S$ of S. Thus the second part is also proved.

(4.2)   If we consider S to be the (additive) totally ordered semi group of non-negative integers or non-negative rationals, or non-negative reals, the order-symmetric group G in which it is imbedded by result (a) above, is seen to be isomorphic with the ordered group of all integers, or all rationals, or all reals. If these examples of S are considered to be assigned a su structure by taking as nuclear base the right-open intervals containing O in S, the associated symmetric gu structure for G, as given by (b) above, will associate the open symmetric intervals around O as the nuclii. Similarly we get the immersion of the half-plane of points (x, y) with $x > O$, or $x = o$ and $y \geq O$ in the full Euclidean real (or rational) plane.

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